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(NASA-CR-159484) USER'S GUIDE TO COMPUTER PROGRAMS JET 5A AND CIVM-JET 5B TO CALCULATE THE LARGE ELASTIC-PLASTIC DYNAMICALLY-INDUCED DEFORMATIONS OF MULTILAYER PARTIAL (Massachusetts Inst. of N79-18343 Unclas G3/39 14096

USER'S GUIDE TO COMPUTER PROGRAMS JET 5A AND CIVM-JET 5B TO CALCULATE THE LARGE ELASTIC-PLASTIC DYNAMICALLY-INDUCED DEFORMATIONS OF MULTILAYER PARTIAL AND/OR COMPLETE STRUCTURAL RINGS

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November 1978

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Prepared for
AEROSPACE SAFETY RESEARCH AND DATA INSTITUTE
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FOREWORD

This report has been prepared by the Aeroelastic and Structures Research Laboratory (ASRL), Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, Massachusetts under Grant No. NGR 22-009-339 from the Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio 44135. Dr. Arthur G. Holms, Mr. Solomon Weiss, and Mr. Robert D. Siewert of the Lewis Research Center served as technical monitors. The cooperation and helpful suggestions of Mr. Raymond W. Palmer and Mr. Richard B. Lantz of NASA-Lewis throughout this research program are much appreciated.

The authors wish to acknowledge that the computations were carried out on an IBM 370/168 system made available at the MIT Information Processing Center. This manuscript was originally released for review to NASA-Lewis in March 1977, and has undergone several minor modifications since that time.

The use of SI units (NASA Policy Directive NPD 2220.4, September 14, 1970) was waived for the present document in accordance with provisions of paragraph 5d of that Directive by the authority of the Director of the Lewis Research Center.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SUMMARY

Described in this report are two user-oriented computer programs, JET 5A and CIVM-JET 5B to predict transient, large, elastic-plastic deflections of single-layer or multilayer (3 layers or less) Bernoulli-Euler structural rings which may be subjected to fragment impact (CIVM-JET 5B), or prescribed externally-applied transient loading, and/or prescribed initial velocity distributions (handled in JET 5A). These structural ring deflections lie essentially in one plane and, hence, are called two-dimensional (2-d). The structural rings may be complete or partial; the former may be regarded as representing a "fragment containment ring" while the latter may be viewed as a 2-d fragment-deflector structure. These two types of "rings" may be either free or supported in various ways (pinned-fixed, locally clamped, elastic-foundation supported, mounting-bracket supported, etc.). The initial geometry of each ring may be circular or arbitrarily curved; uniform-thickness or variable-thickness rings may be analyzed. Strain-hardening and strain-rate effects of initially-isotropic material are taken into account.

An approximate analysis utilizing kinetic energy and momentum conservation relations is used to predict the after-impact velocities of each fragment and of the impact-affected region of the ring; this procedure is termed the collision-imparted velocity method (CIVM) and is used in the CIVM-JET 5B program. This imparted-velocity information is used in conjunction with a finite-element structural response computation code to predict the transient, large-deflection, elastic-plastic responses of the ring. Similarly, the equations of motion for each fragment are solved in small steps in time.

Provisions are made in the CIVM-JET 5B code to analyze structural ring response to impact attack by from 1 to 3 fragments, each with its own size, mass, translational velocity components, and rotational velocity. The effects of friction between each fragment and the impacted ring are included.

SECTION 1

INTRODUCTION

The JET 5A and the CIVM-JET 5B computer programs described in this report are additions to the series of computer programs which are intended to be made available to the aircraft industry for possible use in analyzing structural response problems such as containment/deflection (C/D) rings intended to cope with engine-rotor-burst fragments. These computer programs may also be applicable (a) to crashworthiness problems which are of interest to the automobile industry and (b) to nuclear power plant protective structures.

The features and capabilities of both the present computer programs and earlier ones developed under NASA NGR 22-009-339 are given in a convenient informative tabular summary in Appendix C together with supplementary descriptive material. The reader is urged to examine the Appendix C information in order to make an assessment of which one (or more) of these programs might best suit his particular application, since each computer program has its own specific capabilities and limitations. With regard to the type of applications accommodated, only programs CIVM-JET 4B and CIVM-JET 5B pertain to ring structural response induced by fragment impact; the remaining computer programs cited in Appendix C deal with the transient structural responses of rings which are subjected to prescribed (1) transient distributed external loads or (2) a distributed initial velocity field.

The JET 5A and CIVM-JET 5B programs, written in FORTRAN IV, permit one to predict the large-deflection, two-dimensional, elastic-plastic transient Bernoulli-Euler response of a multilayer[a], multimaterial, hard-bonded[b] ring, which may be either a complete ring or a partial ring. The ring may be subjected to various restraints and supports, including "ring support brackets" (which are treated as "branches") and elastic foundations.

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a: The programs are restricted to 3 or fewer layers but the formulation applies to an arbitrary number of layers.

b: This means that the displacements are defined to be continuous at layer interfaces.

The geometrical shape of the structural ring can be simple circular or arbitrarily curved, and each layer may have independently-varying thickness along the circumferential direction. The material behavior of each layer may be elastic, strain-hardening, and/or strain-rate sensitive. Both of these programs employ the spatial finite-element representation of the ring and the temporal finite-difference solution procedure.

The JET 5A computer program is designed to analyze full rings or partial rings subjected to initial impulsive loading and/or prescribed externally-applied time-dependent forces. On the other hand, the CIVM-JET 5B computer program is designed to analyze the transient responses of structural rings subjected only to rigid-fragment impact. These programs were written in parallel and the main body of the program and input were kept the same to ease the transition from one to the other by the user. The following section of the user's guide will first describe the portion of these programs which are the same and then detail any differences. The governing equations and the solution procedures common to both programs are outlined in Appendix A.

In the CIVM-JET 5B code for predicting the transient responses of structural rings subjected to rigid-fragment impact, energy and momentum considerations are employed in an approximate analysis to predict the collision-induced velocities which are imparted to the fragment and to the affected ring segments. The presence of surface friction between the ring and the impacting fragment is taken into account. The pertinent analytical development and the solution methods which are unique to the CIVM-JET 5B program are presented concisely in Appendix B. The reader is invited to consult Refs. 1, 2, 3, and 4 for background information and a more detailed description of this solution procedure.

Section 2 of this report is devoted to describing the general organization and capabilities of each of these programs. The ring structural geometry, supports, elastic restraints, and materials properties accommodated will be described for both programs. The initial-velocity and prescribed external-loading provisions and the associated solution procedure for JET 5A are described. Then the fragment-ring collision-interaction analysis procedure and the associated transient response solution procedure for CIVM-JET 5B are discussed.

Next in Section 3, the main programs and subroutines for both of these programs are described. Since the formulation and solution of these programs is quite similar, many of the subroutines are used interchangeably between the two. These common subroutines are described first and then any subroutines particular to each of the programs are listed. This procedure will be followed throughout the remainder of this user's guide. Included in Section 3 is a partial list and explanation of the variable names used, first those common to both JET 5A and CIVM-JET 5B and then those variable names particular to each separate program.

A discussion of the conventions used in JET 5A and a detailed explanation of the required input and its resulting output follows in Section 4. Section 5 is a similar presentation for CIVM-JET 5B including only that information which differs from that which is common to JET 5A. A complete listing of the FORTRAN IV code for all of the subroutines, first those common to both programs and then those particular to each program, appears in Section 6.

Illustrative examples of the use of JET 5A and CIVM-JET 5B are given in Subsections 7.1 and 7.2, respectively of Section 7. These examples are presented with their associated input and output as illustrations of the capabilities of these programs, and to aid the user in checking the adaptation of these programs to his computer system.

SECTION 2

GENERAL DESCRIPTION OF THE JET 5A AND THE CIVM-JET 5B PROGRAM

Both of the cited programs are described briefly in this section. Common to both programs are ring geometry, supports, elastic restraints, and material properties; accordingly these matters are discussed in Subsection 2.1. Features that are unique to the JET 5A code include (a) the initial-velocity and external-loading options and (b) the associated solution procedure; these matters are discussed in Subsections 2.2 and 2.3, respectively. Since CIVM-JET 5B accommodates only structural response to fragment impact, Subsection 2.4 contains a description of the ring-fragment collision-interaction analysis and the associated solution procedure.

2.1 Ring Geometry, Supports, Elastic Restraints, and Material Properties

In the present analysis, the transient structural responses of the ring are assumed to consist of planar (two-dimensional) deformations. Also, the Bernoulli-Euler (or Kirchhoff) hypothesis is employed; that is, transverse shear deformation is excluded.

Both the JET 5A and the CIVM-JET 5B computer programs can treat multilayer structural rings. Each layer may be of different material, but perfect bonding at each interface is assumed and hence the displacement fields are continuous across each interface. In addition, each layer may be of independently-varying thickness; however, the total thickness remains small compared with the circumferential dimension of the ring. The cross section of each layer is assumed to be rectangular in shape, and the centroidal axis of a conveniently-chosen* layer (see Fig. 1) is employed as the circumferential reference axis of the multilayer ring.

The structure can be either a complete or a partial ring. The geometric shape of the circumferential axis of the ring can be circular or arbitrarily curved. The outward-normal direction is defined in such a manner that as one moves along the circumferential axis in the positive η direction from an arbitrary reference point, the outward-normal direction is always toward one's left as shown in Fig. 2, where XYZ is the global reference Cartesian coordinate system with the X-axis pointing out of the paper. At any point on the circumferential axis, $\bar{i}$ is a local unit vector defined in the same

*See Appendix A.

direction as the +X axis, $\bar{a}$ is a unit tangent vector along the positive circumferential axis direction, and $\bar{n}$ is a unit outward-normal vector which is defined by the right-hand rule as $\bar{n} = \bar{i} \times \bar{a}$. Once the positive circumferential direction is defined, the outward-normal direction is then determined accordingly (see Fig. 2). For the CIVM-JET 5B code, the positive circumferential direction must be chosen so that the positive outward-normal is directed toward the "outside" of the C/D structure such that fragment impact can occur only on the "inside" of the C/D structure.

In the spatial finite-element analysis, the ring is represented by an assemblage of discrete (or finite) elements compatibly joined at the nodal stations. The geometry and nomenclature of a typical arbitrarily curved ring element are shown in Fig. 3, where the deformation plane is η,ζ and the coordinates η along, and ζ outward-normal to the centroidal axis of a conveniently-chosen layer are employed as the reference coordinates of the multilayer beam element. The nodal number is increased along the positive circumferential direction.

The behavior of each finite-element is characterized by a knowledge of the four generalized displacements: v, w, $\psi = (\partial w/\partial \eta) - (v/R)$, and $\chi = (\partial v/\partial \eta) + (w/R)$ at each of its nodal stations where v and w are the reference plane displacements in the circumferential and the normal direction, respectively; R is the radius of curvature. The displacement within each finite-element is represented by a cubic polynomial in η for the circumferential displacement v and a cubic polynomial in η for the normal displacement w, anchored to the four generalized nodal displacements at each node (see Appendix A and/or Ref. 1 for further details). For application to arbitrarily-curved, variable-thickness, ring structures, the finite elements are described by reading in at each nodal station the global Y and Z coordinates, the slope (the angle between the tangent vector and the +Y axis), and the thickness of each layer. Within each finite element, the slope is approximated by a quadratic function in η and the thickness of each layer is approximated as being piecewise linear between nodes.

As for the support conditions of the structure, these programs include three types of prescribed nodal displacement conditions (see Fig. 4a):

(1) Symmetry* $(v = \psi = 0)$

*Not accommodated in CIVM-JET 5B

(2) Ideally-Clamped $(v = w = \psi = 0)$

(3) Smoothly-Hinged, Pinned $(v = w = 0)$

and two types of elastic restraints (see Fig. 4b):

(a) Point elastically restrained (elastic restoring spring) at given locations (3 directions: normal, tangential, and rotational)

(b) Distributed elastically restrained (elastic foundation) over a given number of elements (3 directions: normal, tangential, and rotational).

A global effective stiffness matrix supplied by the elastic foundation and/or the restoring springs will be evaluated in the program from the virtual-work statement for cases in which the structure is subjected to one or both of these two types of elastic restraints.

The 2-d containment/deflector (C/D) structure may also be regarded as being supported by attachment brackets as depicted, for example, in Fig. 4c. These attachment brackets (or branches) are idealized to behave in the 2-d fashion shown in Fig. 4d. These brackets are modeled as consisting of a single-layer, variable-thickness, 2-d structure of arbitrary initial shape in the plane of the C/D structure, and are connected compatibly with the C/D structure; the other end of each bracket may be supported in any of the common fashions (clamped, pinned, elastic support, etc.). The programs provide for a maximum of five support brackets. In the fragment attack (CIVM-JET 5B) usually only the C/D structure suffers physical impact; however, if the analyst has a physically plausible situation wherein the idealized support bracket could be impacted by a fragment (such a case is depicted in Fig. 4d), the impacted portion must be defined as the main C/D structure since impacts on a branch are not accommodated in the program. It should be noted, however, that the actual brackets in the bracket-supported C/D structure (see Fig. 4c) must undergo 3-d deformation -- this aspect is not accommodated in the present 2-d model. Finally, a support bracket (or branch) may be attached to any nodal station of the main 2-d C/D structure.

Each layer of material can be of elastic, or elastic, perfectly-plastic or elastic-strain-hardening behavior, and the material properties of each

branch can vary from the properties of the main structure. The strain-rate effects of the material can also be taken into account. In the present analysis, the strain-hardening material is accounted for by using the "mechanical sublayer model" (Ref. 1). A useful feature of this model is its inclusion of kinematic hardening and the Bauschinger effect. The strain-rate effect is approximated by assuming that the uniaxial stress-strain curve is affected by strain-rate only by a quasi-steady increase in the yield stress above the "static" value (Ref. 1).

2.2 Initial-Velocity Provisions and/or Externally-Applied Forces for JET 5A

2.2.1 Initial Velocity Provisions

The initial velocity distribution is specified by reading in the initial nodal velocities. Three ways are available to describe these distributions (see Fig. 5):

(1) Arbitrary distribution by prescribing nodal initial velocities, $\dot{v}$, $\dot{w}$, and $\dot{\psi}$ at certain nodes of the structure.

(2) One or more local uniform initial normal velocity values, $\dot{w}$, distributed over certain elements of the structure, and/or

(3) One or more local sine-shaped distributions of initial velocity in the normal direction, distributed over certain elements of the structure.

2.2.2 Transient Externally-Applied Prescribed Loads

The transient externally-applied loads, $F(\eta,t)$ are assumed to be expressible as

$$F(\eta,t) = g(\eta)\, f(t) \tag{2.1}$$

where $g(\eta)$ is the prescribed spatial distribution function and $f(t)$ denotes the amplitude time history. These quantities are described in the program as follows (see Fig. 6):

(a) The function $f(t)$ can be arbitrary and is represented by a series of coordinates in time which specify values of characteristic two-component (normal and circumferential) force-versus-time curves.

The program then linearly interpolates between time points to obtain values of forces at intermediate times by:

$$f(t) = f_m + \frac{f_{m+1} - f_m}{T_{m+1} - T_m}(t - T_m) \tag{2.1a}$$

where f_m and f_{m+1} are the amplitudes of the forces at some user-specified times T_m and T_{m+1}. The quantity f(t) is found by this interpolation in the time interval (T_m to T_{m+1}) linearly in terms of f_m and f_{m+1}.

(b) The spatial distribution of the forces acting on the ring is described through the following three forms:

(1) One or more concentrated loads prescribed at certain locations.

(2) One or more local uniform load distributions specified over given numbers of elements.

(3) One or more local half sinusoidal-shape load distributions specified over given numbers of elements (this distribution is approximated as being piecewise linear within each element).

Corresponding to this general distribution of externally-applied loads, a set of virtual-work equivalent (or consistent) nodal loads is evaluated in the program.

2.3 Solution Procedure for JET 5A

The spatial finite-element approach is utilized in conjunction with the Principle of Virtual Work and D'Alembert's Principle to obtain the equations of motion of the structural ring which is permitted to undergo large-deflection elastic-plastic transient deformations. In the interest of conciseness and convenience in this report, the user is invited to consult Ref. 1 and/or Appendix A for a detailed derivation and discussion of the equations of motion. For present purposes, it suffices to note that the governing equations of motion for the complete assembled discretized structural ring may be written in the following form:

$$[M^*]\{\ddot{q}^*\} + ([K^*] + [K_s^*])\{q^*\} = \{F^*\} + \{F_q^{*NL}\} + \{F_p^{*L}\} + \{F_p^{*NL}\} \tag{2.2}$$

where

$\{q^*\}$ and $\{\ddot{q}^*\}$	are the global generalized displacement and acceleration.
$[M^*]$	is the consistent mass matrix of the complete structure.
$[K^*]$	is the usual stiffness matrix of the complete structure.
$[K_s^*]$	represents the effective stiffness matrix supplied by the elastic foundation and/or the restraining spring.
$\{F^*\}$	denotes the prescribed externally-applied generalized loading acting on the structure.
$\{F_q^{*NL}\}$	represents a "generalized loads" vector arising from large deflections and is a function of quadratic and cubic displacement terms -- a nonlinear force contribution.
$\{F_p^{*L}\}$	is the generalized loads vector arising from the presence of plastic strains, and is associated with the linear terms of the strain-displacement relations.
$\{F_p^{*NL}\}$	is a generalized loads vector of origin similar to $\{F_p^{*L}\}$ but is associated with the nonlinear terms of the strain-displacement relations.

The resulting equation of motion, Eq. 2.2, is solved through the use of the Houbolt operator (4-point backward finite-difference operator) whereby one obtains a recurrence equation which provides a solution step-by-step in finite-time increments. In the following, the general solution process is described briefly.

First, information is provided to define the geometry of the ring including its prescribed-displacement conditions and elastic restraints. In addition, the ring material property constants, and the prescribed initial velocity and/or the prescribed applied transient external loading are defined. Also defined are the structural discretization information and numerical integration data. It should be mentioned that Gaussian quadrature is employed in the present analysis to evaluate the element-property matrices -- this requires that the stresses and strains be evaluated at a selected finite number of Gaussian stations over the "spanwise" and depthwise region of each layer of each finite

element. Next, the mass matrix and the stiffness matrix for the entire structure are evaluated by assembling the element mass and stiffness matrices. Then the proper prescribed displacement conditions are imposed and a reduced mass matrix and stiffness matrix are obtained by deleting the corresponding rows and columns associated with those generalized displacements which are prescribed to be zero. Also constructed are the discrete-element property matrices that do not change with time (and remain constant throughout the program), such as the matrices relating strain to the nodal generalized displacements, the equivalent nodal load vector and actual externally-applied load transformation matrices, etc.

Starting from a set of given initial conditions at time t_o on the generalized nodal displacements, nodal velocities, and externally-applied forces, the generalized nodal displacements and displacement increments are computed for the first time increment Δt. Next, the strain increments developed from t_o to t_1 at every Gaussian station (or point) required over and depthwise through each finite element are calculated. From a knowledge of the prescribed initial stresses (if any) and the strain increments, one can determine the stress increments, the stresses and/or the plastic strains and the plastic strain increments through the use of the pertinent elastic-plastic stress-strain relations including the plastic yield condition and flow rule. Next, one can calculate the equivalent generalized load vectors arising from large deflections and plastic strains. Also, the prescribed generalized load vector representing the externally-applied loads at the present time step is calculated. Then, the proper recurrence equations, which is the finite-difference representation of the equations of motion, are solved to obtain the nodal generalized displacements and displacement increments of the next time increment. The process then proceeds cyclically for as many time steps as desired. Finally, it should be noted that the triple-matrix-factorization scheme is employed to solve the system of ordinary algebraic equations.

For present purposes, the above general description is considered to be adequate; one may consult Appendix A and Refs. 1-3 for a more detailed discussion of the solution and evaluation process.

2.4 Fragment/Ring Collision-Interaction and Solution Procedure for CIVM-JET 5B

For analyzing the collision-induced transient responses of two-dimensional containment and/or deflector rings and fragment motions, the fragment is idealized as a non-deformable fragment of circular configuration as depicted for

example, in Fig. 7. The modeled-fragment diameter, mass, mass moment of inertia, and velocity components are specified by the user to "correspond" with those of the actual fragment.

The process called the collision-imparted velocity method (CIVM) is used for the collision-interaction analysis in the CIVM-JET 5B program (see Refs. 1-3). In this process, energy and momentum considerations are employed to predict the collision-induced velocities which are imparted to the fragment and to the impact-affected zone of the ring. Also, the following simplifying assumptions are invoked:

(1) The collision process is instantaneous and involves only the fragment and the impact-affected zone of the target ring. The impact-affected zone is defined as the fraction of the ring that responds to fragment impact instantaneously with momentum changes. The size of the impact-affected zone of the ring can be estimated from the speed of a longitudinal wave or from semi-empirical data.

(2) In an overall sense, the fragment is treated as being rigid but at the "immediate contact region" between the fragment and the struck ring the collision process is regarded as acting in a perfectly elastic ($e = 1$), perfectly inelastic ($e = 0$), or an intermediate fashion ($0<e<1$), where e represents the coefficient of restitution.

(3) The colliding surfaces of both the fragment and the target ring may be either perfectly smooth ($\mu = 0$) or may be "rough" ($\mu \neq 0$), where μ denotes the coefficient of sliding friction. Hence, respectively, force and/or momentum (or velocities) are transmitted only in the normal-to-surface direction or in both the normal and the tangential direction.

(4) During the collision, the contact forces are the only ones considered to act on the impact-affected region of the ring and in an anti-parallel fashion on the fragment. Any forces which the ring segment on either side of the impact-affected region may exert* on that segment as a result of this collision are considered to be negligible because instantaneous momentum transfer to the impact-affected region is assumed.

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*Such forces are termed "internal forces" as distinguished from the "external impact forces".

(5) To avoid unduly complicating the analysis and because of the smallness of the arc length of the ring finite elements, each affected ring element is treated as a straight beam segment (see Fig. 8) in the derivation of the impact inspections and equations. However, for modeling of the ring itself for transient response predictions, the ring is treated as being arbitrarily curved and of variable thickness.

An information flow schematic of the CIVM and ring/fragment transient response solution procedure is shown in Fig. 9. Briefly, the analysis procedure indicated in Fig. 9 consists of the following principal steps:

1. <u>Motions and Positions of Bodies</u>

The motions of the fragment and of the containment and/or deflector ring are predicted and the (tentative) region of space occupied by each body at a given instant in time is determined.

Modeling of the C/D ring structure is carried out as already described for the JET 5A analysis, except that a diagonal "lumped" mass matrix is employed (see Appendix B). The justification for the use of lumped mass instead of consistent mass is outlined next. A comparison of numerical results obtained using lumped mass vs. consistent mass, given in Ref. 1, for ring-type structures shows similar results for both mass systems. Reduced storage requirements and additional savings of computation time in each time step because of the simple form of the lumped mass matrix, makes the use of a lumped mass matrix computationally efficient. Finally, in the collision-interaction analysis, the element (and structure) mass properties are assumed to be lumped at the nodal points. Thus, for consistency, the mass properties of the ring structure used in the global timewise solution procedure should also be nodal lumped masses. Also, since no prescribed externally-applied forces act on the ring, the form of the governing equations of motion is given by Eq. 2.2 except that $\{F^*\} = 0$.

Prior to fragment-ring impact, the ring structure is assumed to be stationary in its undeformed state and the (one or more) idealized fragment is moving with known translational and rotational velocities toward the ring. The step-by-step solution procedure is carried out in small steps Δt in time by employing Houbolt timewise operator.

2. Collision Inspection

Next, an inspection is performed to determine whether a collision has occurred during the small increment (Δt) in time from the last instant at which the body locations were known to the present instant in time at which the body-location data are sought. If a collision has not occurred during this Δt, one follows the motion of each body for another Δt, etc. However, if a collision has occurred, one proceeds to carry out an (approximate) calculation of the time of fragment-ring contact.

3. Contact-Time Calculation

The fragment and ring-node positions, velocities, and accelerations are known at an instant in time prior to ring-fragment collision. Using this information, the (approximate) time of ring-fragment contact (within a small increment, Δt, in time), and the point of contact on the ring are calculated. When this information has been obtained, one then proceeds to carry out a collision-interaction calculation.

4. Collision-Interaction Calculation

In this calculation energy and momentum conservation relations are employed in an approximate analysis to compute the collision-induced changes in (a) the velocities V_f (translation) and ω_f (rotational) of the fragment and (b) nodal velocities of the ring impact-affected segments. The coordinates which locate the positions of the fragment and of the affected segments are thereby corrected from their tentative uncorrected-for-impact locations.

One then returns to step 1, and the process is repeated for as many time increments as desired.

The details of this analysis procedure as well as various considerations and simplifying assumptions employed are discussed further in Ref. 4 and Appendix B.

SECTION 3

DESCRIPTION OF PROGRAMS AND SUBPROGRAMS

3.1 Program Contents

The following three subsections present a brief description of the subroutines which are common to both the JET 5A and the CIVM-JET 5B program (Subsection 3.1.1). Then the MAIN programs and subroutines unique to each program, JET 5A and CIVM-JET 5B, are presented in Subsections 3.1.2 and 3.1.3, respectively.

3.1.1 Subprograms Common to JET 5A and CIVM-JET 5B

This group consists of the following 14 subprograms:

ASSEF — This subroutine assembles the generalized nodal load vectors (due to large-deflection elastic-plastic effects) of each individual element into a generalized nodal load vector for the structure as a whole.

ASSEM — This subroutine updates the structural mass (and/or stiffness) matrix as the element mass (and/or stiffness) matrices are generated. The components of the assembled structural mass matrix [M*], which is a symmetric matrix, are stored in a linear-array form; only the lower triangular part of [M*] need be and is stored (row-wise) starting with the first nonzero element in the row and ending with the diagonal term. Similar handling of the assembled stiffness matrices ([K*] and $[K^*_s]$) of the structure is employed.

BRAN — This subroutines reads the geometry, boundary constraints, and elastic restraints for a branch. The global numbering system of the main structure is then modified to include the branches. BRAN establishes arrays which contain information facilitating the rotations required in other subroutines. It also establishes identifier arrays which distinguish between elements of the main structure and elements of the various branches.

ELMPP — This subroutine evaluates the element mass matrix [m], and element stiffness matrix [k], for each discrete element, and

then performs discrete element assembly to form [M*] and [K*] for the complete structure with respect to global coordinates. Next, the prescribed displacement conditions (if any) are imposed on [M*] and [K*] to form restrained matrices. Also evaluated are the transformation matrices between the strain at each spanwise checking (Gaussian) station and the generalized nodal displacement conditions of the element.

ERC — Imposes the proper prescribed displacement conditions to the [M*] and/or [K*] matrices by restraining the corresponding rows and columns of the matrices

FAC — FAC factors a symmetric matrix [B], into a lower triangular matrix [L], a diagonal matrix [D], and an upper triangular matrix $[L]^T$; $[B] = [L]\ [D]\ [L]^T$.

IDENT — The IDENT subroutine is used to print out the values of certain input parameters at the beginning of the run, and is used to identify the type of run that is being made.

MINV — Performs the matrix inversion; a standard Gauss-Jordan inversion method is used.

ØMULT — Computes various linear arrays (in which a two-dimensional matrix is stored) and vector products. A vector results.

QREM — Evaluates the effective stiffness matrix $[K_s^*]$, supplied by the elastic foundations and/or the restoring springs, and then imposes the prescribed displacement conditions on $[K_s^*]$ accordingly.

RØTAT — This subroutine generates the transformation matrix necessary to rotate from the global displacement system to the element displacement system. This matrix is then applied to the element [k] matrix, the displacement vector and the equivalent load vector (as required) to perform the rotation for the connecting branch elements and any elements containing discontinuities.

SØLV — Performs two back substitutions involving the triple factorization of a matrix to obtain the solution of a matrix equation.

STRESS — This subroutine evaluates the generalized load vectors, ($\{F_q^{*NL}\}$ + $\{F_p^{*L}\}$ + $\{F_p^{*NL}\}$ of Eq. 2.2) arising from the presence of large-deflections and plastic strains. First, the stresses and plastic strains are determined at each quadrature station, which involves the use of the strain-displacement relation and the stress-strain relation. The strain-hardening and strain-rate sensitivity effects are taken into consideration. Next, the appropriate Gaussian integration scheme is used to form the element generalized nodal load for each discrete element, and finally, an assembled generalized nodal load vector is calculated.

TSTEP — This subroutine is called during each problem run to compute Δt_{ref}. It finds the highest natural frequency, ω_{max}, in the mathematical model of a corresponding linear dynamic system $[M^*] \{\ddot{q}^*\} + [K^*] \{q^*\} = 0$ by using an iteration process, and then calculates a value of $\Delta t_{ref} = (2/\omega_{max})$. Will be used to estimate an appropriate Δt.

3.1.2 Subprograms Unique to JET 5A

This group consists of the following 4 subprograms:

MAIN — Reads the ring geometry, material property data, the structural discretization information, and/or the prescribed displacement conditions and elastic restraints. It computes the quantities that are constant throughout the program and initializes most of the variables used in the subroutines. It controls the logical flow of information supplied by the various subroutines and the overall time cycle.

IMPULS — The information for the initial generalized nodal velocities is read in. This subroutine also sets the initial generalized nodal displacements, the initial stresses, and the initial plastic strains to be equal to zero.

LØADEQ — Computes the transformation matrices between the element generalized (virtual-work equivalent) nodal load vectors and the externally-applied mechanical load which may be concentrated, uniformly distributed, and/or linearly distributed within the element.

LØADFT — This subroutine reads the data pertaining to the subsequent time-dependent externally-applied loads and uses this data to compute the element generalized load vector; subsequently, an assembled generalized load vector for the whole structure is formed at each step of calculation.

3.1.3 Subprograms Unique to CIVM-JET 5B

This group consists of the following 4 subprograms:

MAIN — Reads the ring geometry, material property data, the structural discretization information, and/or the prescribed displacement conditions and elastic restraints. Also, read in are the fragment geometry parameters and the fragment velocity components. It computes the quantities that are constant throughout the program and initializes most of the variables used in the subroutines. It controls the logical flow of information supplied by the various subroutines and the overall time cycle. Also, the lumped mass matrix [M*] is generated by this routine and stored in row form.

IMPACT — This subroutine is the controlling routine for carrying out the search for impact occurrence involving one of N fragments on each element of the ring for all fragments considered. When it is determined that a fragment-ring collision has taken place, IMPACT controls the application of appropriate correction factors to the velocities of the fragment and the nodal points of the affected elements.

IMPCTE — A slave subroutine of IMPACT. This subroutine calculates and applies the appropriate correction factors to the velocities

of the fragment and the nodal points of the elements affected when a fragment-ring collision has occurred.

PENTRN — A slave subroutine of IMPACT. Given the position of the fragment and ring nodes and the geometry of the fragment and idealized ring structure, this subroutine determines whether any "overlapping" (penetration) exists between the fragment geometry and the ring geometry.

3.2 Partial List of Variable Names

The following subsections give a brief list and defination of the most important and/or commonly used variable names.

3.2.1 Variables Common to JET 5A and CIVM-JET 5B

A(I,J)	[A], an 8x8 matrix defines the transformation between the element generalized nodal displacements {q} and the parameters {β} in the assumed displacement field of each element. It is destroyed in computation and is replaced by its inverse $[A^{-1}]$.
AEP(I,J,K)	Transformation matrix which relates strain at Ith additional strain point to the generalized nodal displacements of the element on which it is located.
AL(I)	Element arc length of the Ith element.
AMASS(I)	The lower triangular part of the symmetric structural mass matrix [M*] (stored in a linear-array form of a size ISIZE). Later on, it is destroyed in calculation and is replaced by a lower triangular factorized matrix.
ANB(I)	Same as ANG(I); applies to initial input for branch nodes.
ANG(I)	The slope, which is the angle between the tangent vector and the +Y axis, at the Ith node.
ANGDB ANGDI(I)	The slope, which is the angle between the tangent vector and the +Y axis, at the Ith slope discontinuity. ANGDB refers to initial input for branches.
APHA	The angle between the chord connecting the first node of the element to the second node, and the +Y axis.
ASFL(I,J,K,L)	Stress and/or plastic strain weighting factor on the Lth sub-layer in the Kth depthwise Gaussian point at the Jth spanwise Gaussian station of the Ith element.
AXG(I) AWG(I)	Input vectors with dimension NOGA: contain Gaussian quadrature constants, x_i, and weights, w_i of

$$\int_0^1 f(x)\,dx = \sum_i f(X_i)\,W_i$$

employed in the spanwise integration over each element.

AZET(I)	The location along an element's centroidal axis of the Ith additional strain point.
B(L)	Width of the ring (inches); L=1 for main structure; $L \geq 2$ for branches.
BEP(IR,J,I,K)	Transformation matrix which relates the strain at the Jth spanwise Gaussian station to the generalized nodal displacements of the IRth element ($[D_I]$, I = 1,2,3, see Eq. A.14a).
BI(L)	Same as BIG(L), for largest average nodal strain.
BIG(L)	The largest computed strain at the Gaussian stations for the Lth substructure, up to the present cycle. It should be noted that strains are computed at every cycle. L=1 for main structure, $L \geq 2$ for branches.
BIGA(L)	The largest computed strain at the additional strain points, up to the present cycle.
BINP(I,J) BIMP(I,J)	The longitudinal force and the bending moment, respectively, over the cross section at the Jth spanwise Gaussian station of the Ith element (see Eq. A.24).
BINPP(J) BIMPP(J)	The integration of the plastic strain over the cross-section at the Jth spanwise Gaussian station of each element (see Eq. A.24).
BØNE	The highest natural frequency squared of a corresponding linear dynamic system.
BTIM(L)	Same as BTIME(L); applies to nodes.
BITMA(L)	The time at which the largest computed strain occurs at the additional strain points. L=1 for main structure, $L \geq 2$ for branches.

BTIME(L)	The time at which the largest computed strain occurs at the Gaussian stations.
CINET	Kinetic energy stored in ring at the present time.
CØPY(I) CØPZ(I)	Current global Y coordinate and Z coordinate, respectively, of the Ith node.
DELD(I)	Vector contains the generalized Ith degree of freedom displacement increment during the current time step.
DELTAT	Time-step size used in the program, Δt.
DEP(IR,I,J,K)	Transformation matrix which relates the strain at the Ith node to the generalized nodal displacements of the IRth element.
DENS(M,L)	Density of the Mth material layer of the Lth structural segment. L=1 for main structure, $L\geq 2$ for branches ($lbs\text{-}sec^2/in^4$).
DISP(I)	Vector which contains the generalized Ith degree of freedom displacements at the current time instant.
DROT(L)	Stores information used in rotating a displacement vector into the global system at a point of slope discontinuity.
DS(M,L)	Material constant used in the strain-rate sensitivity formula for the Mth layer. L=1 for main structure, $L\geq 2$ for branches.
DUMMY	A dummy argument in the calling statement of Subroutine ROTAT.
ELAST	Total elastic energy present in the structure at the present time instant.
ELK(I,J)	Element stiffness matrix of dimension 8x8 (Eq. A.24a).
ELMAS(I,J)	Element mass matrix of dimension 8x8 (Eq. A.18b).
ELRP(I,J)	Element effective stiffness matrix of dimension 8x8 supplied by elastic restraints.

EPASI EPASØ	Axial strain on the inner and outer surface, respectively, at an additional strain point.
EPI(I) EPØ(I)	Axial strain on the inner and outer surface, respectively, at the Ith Gaussian station.
EPS(M,L,J)	Input quantities of abscissa of the uniaxial stress-strain curve for the Jth mechanical sublayer material model of the Mth layer. L=1 for main structure, $L \geq 2$ for branches.
EPSI(I) EPSØ(I)	Average axial strain on the inner surface and on the outer surface, respectively, at node I.
FARE FCUR	Midplane axial strain and curvature increment, respectively, at the selected spanwise Gaussian station of each element.
FLVA(I)	Assembled generalized load vector corresponding to large deflections and plastic strain presence; it equals $\{F_q^{*NL}\}+\{F_p^{*L}\}+\{F_p^{*NL}\}$.
FQREF(I)	Assembled generalized load vector supplied by elastic restraints, equals $[K_s^*]\ \{q^*\}$ of Eq. 2.2.
FREQ	The highest natural frequency of a corresponding linear dynamic system of the ring.
GFL(IR,I,J)	Stress and/or plastic strain weighting factor on the Jth depthwise Gaussian point at the Ith spanwise Gaussian station of the IRth element.
GZETA(IR,I,J)	Distance from the centroidal axis to the Jth depthwise Gaussian point at the Ith spanwise Gaussian station of the IRth element.
H(I,M)	Thickness of the Mth layer at the Ith node.
HB(I)	Same as H(I,M), applies only to initial input for branches.
HTH(L)	The branch thickness for the Lth branch at its connecting node.
IBI(L)	Same as IBIG(L), applies to nodes.
IBIG(L)	The element number whose strain, computed at one of its Gaussian stations, exhibits the largest value during the present computer run. L=1 for main structure, $L \geq 2$ for branches.

IBIGA(L)	Same as IBIG(L), applies to additional strain points.
ICØL(I)	Vector, of length NI, contains the column number of the first nonzero entry in the Ith row of the structural mass and/or stiffness matrix.
ICØN	INDICATOR = 0 if last data have been input = 1 if more runs are desired
ICØNT	INDICATOR, if > 0 then the program expects data for a continuation run.
ICP	INDICATOR, which if > 0 indicates that the structure is a complete ring. For a partial ring ICP $\leq$ 0.
IK	Number of discrete elements into which the whole structure is discretized for analysis.
IKK	Total number of nodes.
INUM(I)	Vector of dimension NI contains the corresponding position in the linear-array of the first nonzero entry in the Ith row of the structural mass or stiffness matrix.
IRRUN	A counter: is equal to the number of runs in a single computer submittal.
ISTA(I)	The number of the Gaussian station at which the strain is a maximum.
ISTAA(I)	The number of the additional strain point at which the strain is a maximum.
ISIZE	Number of locations required for the storage of the structural mass or stiffness matrix in linear-array form.
ISUR(L)	Same as ISURF(L), applies to nodes.
ISURA(L)	Same as ISURF(L), applies to additional strain points. L=1 for main structure, L$\geq$2 for branches.

ISURF(L)	INDICATOR = 1 if largest computed strain occurs on inner surface = 2 if largest computed strain occurs on outer surface Refers only to strains calculated at Gaussian stations.
IT	Current time-step (cycle) number.
KRØW(I)	The row number of the Ith irregular row in the structural mass or stiffness matrix.
LATT	Indicates how the branch is attached to the main structure: = -1 inner surface = 0 outer surface = 1,2,3 midsurface of respective layer
LBR(I)	The number of a branch upon which a boundary condition is to be applied.
LHIT(I)	Indicator array. I = branch number. If LHIT(I)=0, branch is not to be impacted; in the present program LHIT(I) <u>must</u> be set equal to zero.
LMT(I)	Array which stores the element numbers of those branch elements where impact cannot occur.
LREF	The layer number whose centroidal axis is conveniently employed as the reference axis of the multilayer structure.
MATT(L)	Indicates the node at which the Lth branch is attached.
MK(I)	Vector which contains new nodal numbers for the main structure, given I as the old nodal number.
MKE(I)	Indicates the substructure to which the Ith element belongs.
MM	Time step (cycle) at which run is to stop.
MNEL(I)	Number of elements in the Ith substructure.
M1	Cycle at which regular printing starts.
M2	Printout will occur every M2 cycles.

MPU	Indicator for punched output: IF MPU = 0, no punched output IF MPU $\neq$ 0, data is punched from last time cycle. This card must be physically changed in the MAIN program.
MREAD MWRITE MPUNCH	Number for the data input tape unit, printed output tape unit, and the punched output tape unit, respectively. These names must be assigned a number in MAIN corresponding to the user's computing facility requirements.
NASP	Number of additional strain points.
NBC(I)	The prescribed-displacement condition identification number.
NBCB(I)	Same as NBC(I), applies to initial input for branches.
NBCØNB	The number of nodes at which the prescribed displacement condition is to be specified: refers only to branches.
NBCØND	The number of nodes at which the prescribed displacement conditions are to be specified.
NBR	Indicates the number of branches that are to be added to main structure (not to exceed 5).
NDEX(I)	The corresponding position in the linear-array of the first nonzero entry in the Ith irregular row.
NDI	Number of branch elements containing a slope discontinuity.
NDIS	The number of elements containing a slope discontinuity.
NEDI(I)	The main structure element number of the Ith element containing a slope discontinuity.
NEDIB(I)	The branch element number of the Ith branch element containing a slope discontinuity.
NELT(I)	Number of elements in the Ith branch.
NFL	The number of depthwise Gaussian points through the thickness of each layer for the numerical evaluation of stress resultants

	(axial forces and bending moment) at each spanwise Gaussian station.
NI	Total number of degrees of freedom (unrestrained); it equals the number of nodes times 4. Also, it is the number of rows in the assembled structural mass or stiffness matrix.
NIRREG	Number of irregular rows in the assembled structural mass or stiffness matrix.
NLAY	The number of layers used in the hard-bonded composite ring.
NØDBB(I)	The node number along branch (I) at which a boundary condition is to be applied.
NØDEB(I)	The node number at which the prescribed displacement condition NBC(I) is to be specified.
NØDP(I)	Nodal number (from main structure numbering system) at which the Ith branch starts.
NØGA	The number of Gaussian stations to be employed for the spanwise numerical integration of the element properties over each element.
NØRP NØRU	The number of point elastic restraints (elastic restoring springs) and the number of locally distributed elastic restraints, respectively, which are to be specified over the structure.
NQR	Indicator, which if > 0 indicates that this structure is subjected to elastic restraints (point and/or distributed).
NREADF	Dummy variable which controls the reading in of force-time data.
NREL(I)	The element number at which the Ith point elastic restraint is to be specified.
NRST(I) NREU(I)	The first element and the number of elements, respectively, over which the Ith distributed elastic restraint is to be specified.

NSFL(M,L)	Equals the number of mechanical sublayers in the strain-hardening material model; also is the number of coordinate pairs defining the piecewise linear stress-strain curve of the substructure's material. M = material layer number. L = 1 for main structure, L $\geq$ 2 for branches.
NV1, NV2, NV3	User specified dimension sizes for number of elements, number of total depthwise Gaussian stations, and number of mechanical sublayers, respectively.
NVEC(I,J)	Array containing nodal numbers which form the end points of the Ith element. J = 1 or 2 [First or second node, number clockwise for main structure, outwards for branches, and inwards for a branch attached to node 1 of a partial ring.]
P(M,L)	Constant used in the strain-rate sensitivity formula for the Mth layer. L = 1 for main structure, L $\geq$ 2 for branches.
PIE	Represents π = 3.141592653589793.
PLAST	Total plastic work done on the structure up to the current time step (mechanical work dissipated during plastic flow).
REX(I)	The length coordinate along the centroidal axis from the node NREL(I) at which the Ith point elastic restraint is to be specified.
RFACTR	Strain rate factor used in the stress calculation.
ROT(I,J)	Array which contains information needed to rotate a stiffness matrix. I = Number of branch J = 1 or 2 ROT(I,1) = 0.0 if Ith branch connects to first node of main structure. Equals 1.0 for all other connecting points. ROT(I,2) = Angle of rotation.
RWORK	Total energy stored in ring up to the current time.

SCTP, SCTY	The tangential and normal translational restoring spring elastic constants, respectively.
SCRP	The rotational restoring spring elastic constant.
SCTU, SCTW	Tangential and normal translational elastic foundation stiffness constants, respectively.
SCRU	Elastic foundation modulus in torsion.
SIG(M,L,J)	Input quantities for the ordinate of the uniaxial static stress-strain curve for the Jth mechanical sublayer material model of the Mth layer. $L = 1$ for main structure; $L \geq 2$ for branches.
SNØ(M,N,L)	Uniaxial static yield stress of the Nth mechanical sublayer material model, for the Mth structural layer. $L = 1$ for main structure; $L \geq 2$ for branches.
SNP(I,J,K,L)	The total plastic strain of the Lth mechanical sublayer at the Kth depthwise Gaussian point at the Jth spanwise Gaussian station of the Ith element.
SNS(I,J,K,L)	Axial stress of the Lth mechanical sublayer at the Kth depthwise Gaussian point at the Jth spanwise Gaussian station of the Ith element.
SNY	Uniaxial yield stress of the mechanical sublayer, taking strain-rate sensitivity into account.
SOL(I)	Contains the solution vector of a series of matrix equations.
SPDEN	Total energy stored in the elastically-restoring springs and/or the elastic foundations at the current time instant.
SPRIN(I)	The assembled effective stiffness matrix supplied by elastic restraints (stored in a linear array form).
STIFK(I)	Assembled structural elastic stiffness matrix, stored in a linear-array form.
TIME	Current time (IT*DELTAT).

TRAN(I,J) — Transformation matrix, used to rotate displacement vector and element stiffness matrices into global coordinates. Used for branch connection and slope discontinuities.

TWG(I), TXG(I) — Input vectors with dimension NFL; contain Gaussian quadrature constants x_i and weights, w_i of

$$\int_{-1}^{+1} f(x)\,dx = \sum_i f(x_i)\,W_i$$

used in the numerical integration of stresses and/or plastic strains through the thickness.

XDIST(I) — Distance from reference axis to attachment point of the Ith branch.

YK(I) — A general work vector. It is finally used to store either the number 1 or 0 for each element (I) to indicate whether a transformation is necessary. YK(I) is used together with ROT(I,J) to identify and aid in rotating an element's stiffness matrix.

YOUNG(M,L) — Elastic (Young's) modulus for the Mth structural layer (the slope of the 1st segment in the piecewise linear approximation of the uniaxial stress-strain curve).

$L = 1$ for main structure; $L \geq 2$ for branches.

Y(I), Z(I) — Initial Y coordinate and Z coordinate, respectively, of the Ith node.

YB(I), ZB(I) — Same as Y(I) and Z(I); applies only to branch nodal input.

3.2.2 Variables Unique to JET 5A

AMP1FV, AMP1FW — Initial nominal amplitudes (at time TBEGIN) of the externally-applied forces in the tangential and the normal direction, respectively.

AMP2FV AMP2FW	Nominal force amplitudes, in the tangential and the normal direction, respectively, of each succeeding point on the force-versus-time curve to be prescribed.
AMPFV AMPFW	The linearly-interpolated values of the nominal force amplitudes in the tangential and the normal direction, respectively, at the current time instant.
ANGV	Initial angular velocity, $\dot{\psi} = (\partial\dot{w}/\partial\eta - \dot{v}/R)$ at time zero.
ANGV1 ANGV2	Initial angular velocities at the two edge nodes of the local uniform initial normal velocity distributed over certain elements of the structure.
APDEN	Total work done on the structure by externally-applied forces up to the present time step.
CINETØ	Initial kinetic energy imparted to the structure.
CINETT	Total work done by all external agencies (externally-applied forces and initial imported kinetic energy) up to the current time step.
ETA(I)	Equals the length coordinate along the centroidal axis from the node JELEM(I) at which the Ith concentrated load is to be specified on element JELEM(I).
FMECH(I)	Assembled generalized load vector due to externally-applied forces.
IE1 IE2	The first element and the number of elements, respectively, over which the local uniform initial normal velocity is to be prescribed.
IØTA	Number of local uniform initial normal velocity distributions.
IØTB	Number of nodes at which the initial generalized nodal velocity components are to be prescribed.
IØTC	Number of local sine-shaped initial normal velocity distributions.

IS1, IS2	The first element and the number of elements, respectively, over which the local sine-shaped initial normal velocity is to be prescribed.
JELEM(I)	The element number at which the Ith concentrated load is to be specified.
NELF2(I)	The number of elements over which the Ith local uniformly distributed externally-applied load is to be specified.
NELF3(I)	The number of elements over which the Ith local sine-shaped distributed externally-applied load is to be specified.
NLØAD	Equal to 1 means external forces are acting during the current time step; equal to 2 means the forces are not acting.
NØDEV	The node number at which the initial generalized nodal velocity components are to be specified.
NØFT1, NØFT2, NØFT3	The number of concentrated loads, the number of local uniform load distributions, and the number of local sine-shaped load distributions, respectively, which are to be prescribed over the structure.
NREADF	Dummy variable which controls the reading-in of force-time data.
NSTF2(I)	The first element number at which the Ith local uniform load distribution is to be specified.
NSTF3(I)	The first element number at which the Ith local sine-shaped load distribution is to be specified.
NV	Indicator, which if > 0 indicates that initial velocity distributions are to be specified over the structure.
RTØV(I), RTØW(I)	The normalized values of the Ith concentrated load with respect to the nominal amplitudes in the tangential and the normal direction, respectively.

RTØ2V(I) RTØ2W(I)	The normalized values of the Ith local uniform load distribution with respect to the nominal amplitudes in the tangential and the normal direction, respectively.
RTØ3V(I) RTØ3W(I)	The normalized values of the Ith sine-shaped load distribution with respect to the nominal amplitudes in the tangential and the normal direction, respectively.
SLØPEV SLØPEW	Slopes of the piecewise-linear segment approximation of nominal force versus time curve in the tangential and the normal direction, respectively, at the current time instant.
T1 T2	Times at which a linear segment of the force-versus-time curve starts acting and stops acting, respectively.
TBEGIN TFINAL	Times when overall externally-applied forcing function starts acting and stops acting, respectively.
VRAD	The value of the initial tangential velocity to be specified at the node of the element.
WRAD	The value of initial normal velocity to be specified for the local uniform initial normal velocity; also is the peak value of the sine-shaped initial normal velocity distribution.
WRAD1 WRAD2	The values of the initial normal velocity at the two edge nodes of the local uniform initial normal velocity distributed over certain elements of the structure.

3.2.3 Variables Unique to CIVM-JET 5B

ADØT(J)	The angular velocity of the Jth fragment (rad/sec). Positive sign denotes counter-clockwise rotation.
AINT	Relative normal velocity between the ring impact-affected nodes and an impacting fragment.
ALFA(I)	Angular rotation of fragment (I) (rad).
APN	Fragment-induced impulse normal to the impacted ring element surface.

APT	Fragment-induced impulse tangential to the impacted ring element surface.
CINETF(J)	Kinetic energy stored in Jth fragment up to the present time.
CR(J)	Coefficient of restitution between the Jth fragment and the impacted ring surface.
DALFA(J)	Impact-corrected angular displacement increment of the Jth fragment at the current time step.
DCRTE	Critical distance used in calculating where a positive penetration has occurred between a fragment and a ring element. It is equal to the fragment radius plus one half the mean element thickness.
DDELD(I)	Stores DELD(I) from the previous time step.
DELTR	Equal to time step Δt. Used in impact inspection and correction calculations.
DFCGU(J)	Impact-corrected Y-direction displacement increment applied to the position of fragment J.
DFCGW(J)	Impact-corrected Z-direction displacement increment applied to the position of fragment J.
EFLN(L)	The effective impact length of the ring (inches). L=1 for main structure. $L \geq 2$ for branches.
FACTFN	Impact-induced correction factor applied to the normal-to-impact displacement increment of the attacking fragment at the time of contact.
FACTFT	Impact-induced correction factor applied to the tangential-to-impact displacement increment of the attacking fragment at the time of contact.
FACTFØ	Impact-induced correction factor applied to the rotational displacement increment of the attacking fragment at the time of contact.
FACTN	Impact-induced correction factor applied to the normal-to-impact displacement increment of each affected node.

FACTT	Impact-induced correction factor applied to the tangential-to-impact displacement increment of each affected node.
FCGU(J)	The global Y coordinate of the centroid of the Jth fragment.
FCGW(J)	The global Z coordinate of the centroid of the Jth fragment.
FH(J)	The diameter of the circular disk model of fragment J.
FKT(J)	Initial kinetic energy of fragment J.
FMASS(J)	The mass of the Jth fragment ($lb\text{-}sec^2/in$).
FMØI(J)	The mass moment of inertia of the Jth fragment ($lb\text{-}sec^2\text{-}in$).
IFLAG(I,J)	A flagging matrix which indicates whether element I has been impacted by fragment J during a given time step, Δt.
IMCØ	Indicates the occurrence of an impact in the previous time step.
IMCØU	Indicates the number of impacts up to the present time instant.
JF	The fragment number which is involved in the ring segment impact.
KII	Number of nodes included in the impact-affected region.
MIRP	Indicates the first fragment that is released at a time after the initial impact.
NF	The number of fragments considered to be impacting the ring.
NPP	The number of positive penetrations during time DELTR.
PAL	Fractional distance from point of impact to the first node of the impacted element
PAX	Fractional distance from point of impact to the second node of the impacted element.
QACL(I)	Vector which contains the generalized DOF accelerations for the current time step.

QVEL(I)	Vector which contains the generalized DOF velocities at the current time instant.
RCØS(I) RSIN(I)	Cosine and sine, respectively of the angle that element I makes with the global Y axis. Used in transformation from impact to local and local to global coordinate systems.
RL(I)	Straight line length of ring element I used in the collision inspection and correction analysis.
RMASS(I) RMX(I)	Lumped mass and moment of inertia values, respectively, at ring structure node I.
SINT	Relative tangential velocity between the ring impact-affected nodes and an impacting fragment.
TAII	Time of initial impact.
TANX	Boundary between rolling and sliding friction.
TNJ(J)	Indicates whether or not fragment J has been released before the start of calculations.
TPRIM(J)	Length of time that fragment J has been traveling prior to initial impact of the <u>first</u> fragment.
TU(I) TW(I)	Trial Y and Z coordinates, respectively, of the Ith node during impact calculations.
UDØT(J)	The velocity component of the Jth fragment parallel to the global Y axis.
UNK(J)	Coefficient of friction for the Jth fragment.
VELFA(J) VELFU(J) VELFW(J)	Same as ADOT(J) " " UDOT(J) used in impact calculations. " " WDOT(J)
WDOT(J)	The velocity component of the Jth fragment parallel to the global Z axis.

SECTION 4

USE OF THE JET 5A PROGRAM

4.1 Guidelines for User-Prepared Array Dimensions

The JET 5A program is capable of handling multilayer structures with up to three layers, up to fifty elements, and up to five "mechanical sublayers" to represent the stress-strain behavior of the material. Inherent with this capability is a large computer core requirement. In order to make the program more flexible for the user with a limited budget or a limited computer core, the largest dimensioned arrays are to be user dimensioned in the MAIN program and will be variably dimensioned throughout the subroutines. The user must, therefore, insert his own dimension statements for these arrays at the beginning of the MAIN program, before running the JET 5A computer code. Once the user has set the dimension limits for these arrays, it is unnecessary to change these dimension statements until a run is submitted in which one or more of the dimensions will be exceeded. The user must be warned, however, that the upper limit for the dimensions (as mentioned earlier in this subsection) can not be exceeded, as other dimensioned variables are fixed at these maximum values. It is hoped that with a minimum of interaction between the user and the computer deck, the user will be able to save fifty to sixty percent of the maximum required core, when jobs are run with only one or two layers, or with a few elements.

Listed below are the cards that the user is required to change in the MAIN program:

```
Dimension       ASFL(IK,3,K,NSFL), GZETA(IK,3,K), SNJ(IK, 3,K,NSFL),
                SNP(IK,3,K,NSFL), AEP(IK,3,8), DEP(IK,2,3,8)

Dimension       STIFK(L), SPRIN(L), AMASS(L), QDD(M), REACM(L), REACK(L),
                REAL(L), REAFM(M), REAFK(M)

NV1 = IK
NV2 = K
NV3 = NSFL

MPU = J
```

where

IK	The number of elements.
K	Number of layers times the number of depthwise Gaussian stations, NFL.
NSFL	The number of mechanical sublayers.
L	The number of nodes times 26 plus ten. If there are branches attached to the middle of the main structure, add a cushion of at least 100 to L.
M	The number of nodes times four plus one.
J	Equals 0 if no continuation cards are desired. Equals 1 if continuation cards are to be punched.

4.2 Input Information and Procedure

The information required to punch a set of data cards for a run of the program is presented in a step-by-step manner in this section. The variables to be punched on the nth data card are outlined, and to the right is the format to be used for that card; the definition of and some restrictions for each variable are given directly below. This is done for each card, in turn, until all are described.

Cards 1 through 16 are used to describe the ring geometry, material properties, the finite-element modeling, and the prescribed displacement conditions and/or elastic restraints. Cards 17-27 are used to describe the initial impulsive loads and/or the externally-applied force distributions.

Card 1	Format
IK, ICP, NLAY, LREF, NOGA, NFL, MM, M1, M2, ICON	10I5

where

IK	The number of finite elements used to model the whole ring structure. This number cannot exceed 50 (however, this limitation may be relaxed by a changing of the appropriate dimension statements of the program).
ICP	Indicator, which if >0 indicates that the structure is a complete ring. For a partial ring, ICP$\leq$0.

NLAY — The number of layers used in the hard-bonded composite ring. This number cannot be greater than 3.

LREF — The layer number whose centroidal axis is conveniently employed as the reference axis of the multilayer ring. The first layer of the maximum of 3 layers is defined to be the inside layer of the ring.

NOGA — The number of spanwise Gaussian stations to be used for the spanwise numerical integration over each element in evaluating the element property matrices. NOGA=3 is used in JET 5A.

NFL — The number of depthwise Gaussian points to be used for the numerical integration through the thickness of each layer at each spanwise Gaussian station. This number cannot exceed 6.

MM — The cycle number at which the run is to stop.

M1 — The cycle number at which the regular printout is to begin. M1 must not equal 0.

M2 — The number of cycles between regular printout (i.e., print every M2 cycles).

ICON — Integer that controls the stopping of the entire program:

- = 0 The program will stop after all the required printouts are made for a particular run.
- = 1 The program will expect a new set of Cards 1-27 for another ring problem.

Card 2

NSFL(1,1) ---- NSFL(NLAY,1) 3I5

where

NSFL(1,1) — The number of material mechanical sublayers in the strain-hardening material model for the first layer of the main structure, and equals the number of coordinate pairs

defining the polygonal approximation of the stress-strain curve for that material. NSFL(1,1) can not exceed 5.

Continue until NSFL(NLAY,1) is specified, where NLAY is the total number of layers in the multilayer ring, and NSFL(M,1) can not exceed 5. [M=1, NLAY].

Card 3A

DENS(1,1), DS(1,1), P(1,1) 3D15.6

where

DENS(1,1) The mass density of the first layer material (lb-sec^2/in^4) of the main structure (first substructure).

DS(1,1), P(1,1) The values of the constants D and p, respectively used in the Cowper-Symonds [7] strain-rate sensitivity formula:*

$$\sigma_{yk} = \sigma_{ok}\left(1 + \left|\frac{\dot{\epsilon}}{D}\right|^{\frac{1}{p}}\right)$$

for the first layer of the multilayer ring, where DS=(1/sec), σ_{ok} is the static yield stress of the kth mechanical sub-layer, and σ_{yk} is the corresponding rate dependent yield stress. If the material of ring layer 1 does not exhibit strain-rate sensitivity, set DS(1,1)=0.0 and P(1,1)=0.0.

Card 4AA

EPS(1,1,1), SIG(1,1,1), EPS(1,2,1), SIG(1,2,1) 4D15.6

where

EPS(1,1,1), SIG(1,1,1) The first coordinate pair of strain, ε, and stress, σ, for the first ring layer, which is used to define the polygonal approximation of the first layer's stress-strain diagram. The stress-strain diagram from which these values and those following are obtained must be upwardly-convex with non-negative slopes. (ε(M,L) = in/in, and σ(M,L) = lb/in.) (This is for the main structure which is termed the first substructure.)

*See Ref. 8 wherein values cited for aluminum, for example, are D = 6500 sec^{-1} and p = 4; for mild steel D = 40.4 sec^{-1} and p = 5. For other materials, the user will need to seek appropriate strain rate data from sources such as the Air Force Materials Laboratory, the General Motors Research Laboratory, etc. [7-13] and to deduce approximate values for D and p by data fitting studies.

EPS(1,2,1)
SIG(1,2,1) — The second coordinate pair of the polygonal approximate strain and stress in the first ring layer, of the main structure.

Additional Cards 4AB and 4AC are punched in exactly the same manner as Card 4AA until the number of coordinate pairs equals NSFL(1,1) punched on Card 2 for layer 1. The total number of coordinate pairs must not exceed 5 for any layer. Do not include any unneeded (blank) cards.

Cards 3 through 4 are repeated for each additional layer in the multilayer ring until the number of sets of cards equals NLAY (given in Card 1). The total number of card sets must not exceed 3.

Card 5

B(1), DELTAT — 2D15.6

where

B(1) — The width of the multilayer main structure (inches).

DELTAT — The time step, Δt (seconds) to be employed for the Houbolt timewise integration operator. If the value of Δt is set equal to zero on this card, the program will compute the largest natural frequency, ω_{max}, of the corresponding linear system and will then choose a value $\Delta t = 2\Delta t^{CD}_{max}$, where Δt^{CD}_{max} is the maximum Δt allowed for a linear system using the central difference operator: $\Delta t^{CD}_{max} = 2/\omega_{max}$.

Card 6A

Y(1), Z(1), ANG(1) — 3D15.6

where

Y(1)
Z(1) — Initial Y and Z coordinate, respectively, of the first node (inches).

ANG(1) — The slope (degrees) which is the angle between the tangent vector and the +Y axis at the first node. An angle from the +Y axis to the tangent vector in a counter-clockwise direction is defined as the positive direction (see Fig. 3).

Additional Cards 6B, 6C, ... are punched in exactly the same format as Card 6A until the total number of No. 6 cards equals (IK+1) for a partial ring and equals IK for a complete ring, where IK is the value appearing on Card 1. Also, the following two conditions must be satisfied by ANG(I) (where I is the node number):

(1) $-180^{\circ} < \mathrm{ANG(I)} \leq +180^{\circ}$

(2) An element cannot have a change in slope between its first node and its second node that is greater than 15°. This refers only to the shape of one element (see Fig. 3); slope discontinuities between two elements are handled on Card 8.

Note that for bookkeeping purposes, the nodal slope is defined to be identified with the first end (left-hand end) of the element at that node for structures with continuous slopes. However, where a slope discontinuity occurs on the main structure, a node must be used and two slopes must be given: (1) one given on Card 6A associated with the second end (right-hand end) of the pertinent element and (2) one associated with "end one" (L-H end) of the next element; the item (2) situation is dealt with by Cards 8A, 8BA, 8BB, 8BC, etc.

Card 7A

H(1,1), ... H(1, NLAY), H(2,1) .. 5D15.6

where

H(1,1)	The thickness of the first layer of the ring at node 1 (inches)
H(1,M)	The thickness of the Mth layer of the ring at node 1 (inches)

Card(s) 7B, 7C, ... are repeated in the same format until the thicknesses of each layer of the ring at every nodal station are defined. The total number of data on Cards 7 (with 5 data on each card) should be equal to NLAY*IK for a complete ring and equal to NLAY*(IK+1) for a partial ring.

Card 8A

NDIS I5

where

NDIS — The total number of elements in the main structure having a slope discontinuity at the first node of the element.

If there are no slope discontinuities on the main structure, set NDIS=0 and go to Card 9.

Card 8BA

NEDI(I), ANGDI(I) — 4(I5,D15.6)

where

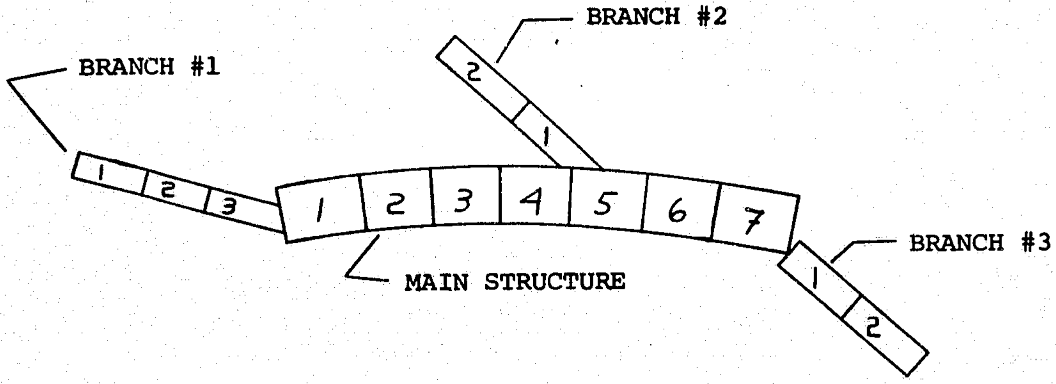
I = 1, NDIS

NEDI(I) — The element (on the main structure) at which the Ith slope discontinuity appears on the element's first node.

ANGDI(I) — The appropriate slope (degrees) for the Ith slope discontinuity; the slope is measured between the tangent vector to the element at the station in question and the +Y axis (see Card 6a ANG(1) for a description of the measurement system).

Additional Cards 8BB, 8BC, etc. are used until all of the "slope discontinuities" are described. (See Fig. 10 for a further description of the discontinuity option.)

The sequence of cards starting with Card 9 and going through Card 9DB contains all of the data for the single layer branches to be applied to the main structure except that elastic restraints must be handled as one unit on Card 16. If no branches are to be applied, Card 9 has NBR=0; then proceed to Card 10. Only 5 branches are allowed, with a maximum of 10 elements in any one branch. A branch may not be connected to another branch. Branches may be attached to any node on the main structure, or to the inner or outer surface of the main structure at any node but only one branch may be connected to a given main-structure node. Note that if a complete ring primary structure is specified, no branch may connect to node 1 of the primary structure. The following sketch shows typical permissible arrangements of the single layer branches:



Note the difference in the numbering schemes for branch 1 compared with branches 2 and 3; the last geometry input card for a branch pertains to its junction with the main structure. Numbering of the primary structure is done independent of any branches. Typical branch numbering is given in the above sketch. Note that all numbering in the above sketch is done in each sub-structure's system. The program will renumber (in a clockwise manner) the entire finite element system.

The following describes the sequence of Cards (9A through 9DB) needed to accommodate branches (these cards are nested in such a way that each branch's material and geometric properties are specified, branch by branch, followed by slope-discontinuity information for all branches, followed by boundary condition information for all branches):

Card 9	<u>Format</u>
NBR	I5

where

NBR — The number of individual branches being added to the main structure ($NBR \leq 5$).
If NBR=0, go to Card 10

Card 9A	
NSFL(1,L), B(L), DENS(1,L), DS(1,L), P(1,L)	I5, 4D15.6

where

L=2, NBR+1 — The branch number is (L-1); the values of these variables when L=1 are equal to the main structure's material.

NSFL(1,L) The number of mechanical sublayers in the strain-hardening model of the material of the (L-1) branch, and is equal to the number of coordinate pairs defining the polygonal approximation of the stress-strain curve of the material (NSFL(L)$\leq$5).

B(L) Width of the (L-1) branch (inches).

DENS(1,L) Mass density of the (L-1) branch (lb-sec^2)/in^4.

DS(1,L), P(1,L) See Card 3A. (L-1) Branch.

Card 9AA

EPS(1,J,L), SIG(1,J,L) 4D15.6

where

J = coordinate pair number $\leq$ 5

(L-1) = branch number $\leq$ 5

EPS(1,J,L), SIG(1,J,L) See Card 4AA for definition of quantities.

Additional Cards 9AB and 9AC are punched in exactly the same manner as Card 9AA until the number of coordinate pairs equals NSFL(L) punched on Card 9A. Do not include any unneeded (blank) cards.

Card 9B

NELT(I), NODP(I), LHIT(I), LATT(I) 4(I5)

where

I = 1,NBR is the branch number

NELT(I) number of elements in Ith branch (NELT(I)$\leq$10)

NODP(I) Node of main structure (in original numbering system) at which Ith branch is attached. See figure on page 42.

LHIT(I) Determines whether or not branch can be impacted:

LHIT(I)=0 No impact

LHIT(I)=1 Impact

Note: This subroutine is used in common with CIVM-JET 5B, set LHIT(I)=0 for JET 5A computer runs.

LATT(I) — Determines where branch is to be attached.

LATT(I) = -1	inner surface
0	outer surface
1,2,3	midsurface of respective layer

Card 9BA

YB(I,J), ZB(I,J), ANB(I,J), HB(I,J) 4D15.6

where

(I = branch number, J = node numer). Nodes are to be numbered from 1 to NELT(I) where node 1 is the first node of a branch (not attachment point). Node NELT(I) is the attachment point to the main structure.

YB(I,J) — Y coordinate of node (inches)

ZB(I,J) — Z coordinate of node (inches)

ANB(I,J) — Tangent angle measured to Y axis (degrees); see Fig. 3.

HB(I,J) — Thickness at node J

Note: See Card 6A [ANG(1)] for sign convention used for ANB(I,J).

Note: If a branch attaches to node 1 of a partial ring (it can not be attached to node 1 of a complete ring), the numbering starts with the branch node farthest away from the attachment point. Therefore, the (NELT+1) node is the attachment point. If the branch attaches to any other node of the primary structure, start numbering with the node immediately after the attachment point. Thus, node NELT will be the node farthest away from the attachment point. However, node (NELT+1) will always be the attachment-point node. Thus nodes 1 to NELT are always

particular only to the branch, and node (NELT+1) is the common node with the primary structure. The subroutine BRAN automatically updates IK (the total number of elements), IKK (number of nodes), and NI (D.O.F.). Therefore, the initial input (Cards 1-8 and 10-15) is punched as though the branches did not exist.

Cards 9BB, 9BC, etc., are punched until (NELT+1) nodes have been described.

Card 9C

NDISB	I5

where

NDISB — The number of elements in the branches having a discontinuity at their first node. (Do not count the discontinuities due to the attachment of the branch to the main structure.)

If there are no discontinuities on the branches, set NDISB=0 and go to Card 9D.

Card 9CA

NEDIB, NBDI, ANGB	2I5,D15.6

where

NEDIB — The element number (along a branch) at which the discontinuity occurs.

NBDI — The branch in which the element NEDIB is contained.

ANGB — The slope (degrees); See Card 6A [ANG(1)] for sign convention used for ANGB.

Cards 9CB, 9CC, etc. follow until the information for all NDISB branch slope-discontinuities has been given.

Card 9D

NBCONB	I5

where

NBCONB — The number of boundary conditions applied <u>only</u> to the branches. (Total B.C.'s on structure $\leq$ 7).
If Card 9D = 0 go to Card 10.

Card 9DA

NBCB(I), NODBB(I), LBR(I) 4(3I5)

where

I =	1, NBCONB
NBCB(I)	Type of boundary condition. See Card 15 for description.
NODBB(I)	The node number of the particular branch on which the B.C. is being applied (see sketch prior to Card 9 description).
LBR(I)	The branch number on which the B.C. is being applied (see sketch).

A total of seven boundary conditions is allowed, including the primary structure and all branches. Therefore, Card 9DB is punched if more than 4 B.C.'s are to be applied to the branches.

The cards grouped under the number 9 contain the complete description of all branches (except for elastic restraints). These cards are nested branch by branch, such that a branch's material and geometric layout are completely described before starting the next branch. After all branches have been described, and the branch slope-discontinuity information has been given, then the boundary conditions are applied to all branches. It should be noted that branches may contain only one material layer.

An example is given below for a main structure containing two branches, each of a different material, and five boundary conditions on the branches. For each material a three mechanical sublayer model is used. The first branch contains two elements, while the second branch has three elements. The first has one slope-discontinuity, the second branch has none. The following list gives the card number (described in this section) in the order they would appear in the input deck:

Branch 1

Card 9
Card 9A
Card 9AA
Card 9AB
Card 9B
Card 9BA
Card 9BB
Card 9BC

go to top of next column

Branch 2

Card 9A
Card 9AA
Card 9AB
Card 9B
Card 9BA
Card 9BB
Card 9BC
Card 9BD

Slope Discontinuities

Card 9C
Card 9CA

Boundary Conditions

Card 9D
Card 9DA
Card 9DB

Card 10

NOP, NASP, NTERF 3I5

where

NOP Indicates the type of strain output desired (given at inner and outer surface)

= 0 Average strain at node

= 1 Average strain at each node plus strain at each Gaussian station

= 2 Average strain at each node plus strain at designated additional points

= 3 Strain for <u>all</u> three of the above options

NASP Number of additional strain points requested; NASP $\leq$ 50

NTERF Indicates whether strain information for the boundary of two material layers is to be printed. If NTERF=0 this

strain information will not be printed. If there are three structural layers in the main structure, then the strains at each of the two interfaces will be printed for each element. If there are only two layers present, then the strains for the one interface will be listed and strains along the reference axis will be listed instead of strains at a second interface. The actual output is governed by the indicator NOP; interface strains are printed for each Gaussian station and for any additional strain points as specified by the value of NOP on Card 10.

If NOP $\neq$ 2 or 3, go to Card 11.

Note: It is suggested that the user use NOP=1 or NOP=3 in order to obtain a complete set of strain output for a first run of a problem. NOP=0 or 2 can be used for additional runs of the same problem in order to reduce output costs.

Card 10A

NSBS(I), NSEL(I), AZET(I) 2I5,D15.6

where

I = 1, NASP

NSBS(I) Number of the substructure on which the additional strain point is requested: NSBS = 1 main structure; if NSBS > 1 the substructure is a branch whose number is (NSBS - 1)

NSEL(I) The element along the NSBS substructure on which additional strain point is requested. No more than 10 additional strain points are allowed on any one element.

AZET(I) Ths $\bar{s}$ coordinate of the additional strain point measured from the first node of the element ($\bar{s}$ is a fractional length (in/in) of the element itself).

Cards 10B, 10C, etc. are used until all the additional strain points have been described.

Card 11

AXG(1), AXG(2), AXG(3) 3D25.16

Card 12

AWG(1), AWG(2), AWG(3) 3D25.16

where

AXG(I), AWG(I) — Vectors, of dimension NOGA, contain Gaussian quadrature constants, x_i and weights, W_i, respectively, for the numerical evaluation of

$$\int_0^1 f(x)\,dx = \sum_i f(x_i)\,W_i$$

The following data appear on Card 11, since NOGA=3: 0.1127016653792585D+00 0.5000000000000000D+00 0.8872983346207415D+00 and the data 0.2777777777777778D+00 0.4444444444444444D+00 0.2777777777777778D+00 on Card 12.

Card 13A

TXG(1), TXG(2), TXG(3) 3D25.16

Card 13B

TXG(4) 3D25.16

Card 14A

TWG(1), TWG(2), TWG(3) 3D25.16

Card 14B

TWG(4) D25.16

Note: If NFL $\leq$ 3, Cards 13B and 14B are eliminated. If NFL > 4 the extra terms are added to Cards 13B and 14B.

where

TXG(I) — Vectors of dimension NFL, contain Gaussian quadrature constants, x_i, and weights, W_i respectively, for the numerical integration of

$$\int_{-1}^{1} f(x)\,dx = \sum_i f(x_i)\,W_i$$

If NFL=4, for example, then the following data appear on Cards 13A, and 13B:

-0.8611363115940530D+00 -0.3399810435848560D+00

0.3399810435848560D+00 0.8611364115940530D+00

and the data

0.3478548451374540D+0 0.6521451548625460D+00

0.6521451548625460D+00 0.3478548451374540D+0

appear on Cards 14A and 14B.

Card 15

NBCOND, NBC(1), NODEB(1), NBC(2), NODEB(2), ... NBC(7), NODEB(7)   10I5

where

NBCOND	The number of prescribed displacement conditions to be specified on the structure. This number must not exceed 7.
NBC(1), NODEB(1)	The identification number and the node number, respectively, for which the first prescribed displacement condition is to be imposed.
NBC(2), NODEB(2)	The second data group of the identification number and node number, respectively, for which the second prescribed displacement condition is to be imposed.

The appropriate form of the data group NBC(I) and NODEB(I) should be repeated NBCOND times. If NBCOND=0, that means there is no prescribed displacement condition to be imposed on the structure; then, leave NBC(I) and NODEB(I) blank.

The prescribed displacement condition identification number can be equal to 1, 2, or 3, depending upon the type of the prescribed displacement condition. Its description follows:

NBC(I)=1	Symmetry displacement condition, setting the degrees of freedom v and ψ at the node NODEB(I) to zero.
NBC(I)=2	Ideally clamped condition, setting v, w, and ψ at node NODEB(I) to zero.

NBC(I)=3 Smoothly-hinged condition, setting v and w at node NODEB(I) to zero.

Card 16

NQR, NORP, NORU 3I5

where

NQR Indicator, which if > 0 indicates that the structure is subjected to elastic restraints (point and/or distributed).

NORP The number of point elastic restraints (elastic restoring springs) which are to be prescribed over the structure. This number must not exceed 4.

NORU The number of local distributed elastic restraints (elastic foundations) which are to be prescribed over the structure. This number must not exceed 4.

If there are no prescribed elastic restraints on the structure, set NQR=0 and leave NORP and NORU blank.

Card 16A and Card 16B are included only if NQR > 0 on Card 16. If NORP=0, skip to Card 16B.

Card 16A

SCTP, SCTY, SCRP 3D15.6

Card 16AA

NREL(1), REX(1), NREL(2), REX(2) ... NREL(4), REX(4) 4(I5,D15.6)

where

SCTP The translational tangential restoring spring elastic constant (lb/in).

SCTY The translational radial restoring spring elastic constant (lb/in).

SCRP The torsional restoring spring elastic constant (in-lb/radian).

NREL(I), REX(I) The element number and the length coordinate along the reference axis from the node NREL(I) of the element,

respectively, at which the Ith point elastic restraint is to be specified.

The data group NREL(I), REX(I) should be repeated NORP times.

If NORU=0 in Card 16, omit Card 16, and Card 17 follows directly.

Card 16B

SCTU, SCTW, SCRU 3D15.6

Card 16BB

NRST(1), NREU(1), ... NRST(4), NREU(4) 8I5

where

SCTU Elastic foundation modulus in translation along the circumferential direction (lb/in^2).

SCTW Elastic foundation modulus in translation along the normal direction (lb/in^2).

SCRU Elastic foundation modulus in torsion (in-lb)/(rad-in).

NRST(1), NREU(1) The first element and the number of elements, respectively, over which the first elastic foundation is to be specified (the first elastic foundation is distributed to element NRST(1), through and including element (NRST(1)+NREU(1)-1).

Note: The element numbers used here must be those defined after branches have been added. See Fig. 12c.

NRST(2), NREU(2) The first element and the number of elements over which the second elastic foundation is to be specified.

Data group NRST(I) and NREU(I) are repeated NORU times.

Cards 17 through 20 are used to describe the initial velocity distributions.

Card 17

NV, IOTA, IOTB, IOTC 4I5

where

NV Indicator, which if > 0 indicates that the initial velocities are to be prescribed over the structure.

IOTA Number of local uniform initial normal velocity distributions.

IOTB — Number of nodes at which the initial generalized nodal velocity components are to be specified.

IOTC — Number of local sine-shaped initial normal velocity distributions.

If there are no initial velocity distributions, set NV=0 and leave IOTA, IOTB, IOTC blank; then skip to Card 21.

If IOTA>0, the following No. 18 Card(s) must be included directly; otherwise, skip to Card 19.

Card 18A

IE1, IE2 — 2I5

Card 18AA

WRAD, WRAD1, ANGV1, WRAD2, ANGV2 — 5D15.6

where

IE1, IE2 — The first element and the number of elements, respectively, over which the first local uniform initial normal velocity is to be prescribed. The number IE2 must be greater than one.

WRAD — The value of the initial normal velocity $\dot{w}_o$ (in/sec) for the first local uniform initial velocity distribution.

WRAD1, ANGV1 — The initial radial velocity $\dot{w}_o$ (in/sec) and initial angular velocity $\dot{\psi}_o$ (rad/sec), respectively, which are to be prescribed on node IE1.

WRAD2, ANGV2 — The initial radial velocity and angular velocity which are to be specified on node IE1+IE2.

Additional Cards 18B, 18BB, and 18C, 18CC ... are punched in the same format, until the total number of cards equals IOTA given in Card 17.

It perhaps should be mentioned that the values of WRAD1, ANGV1 and WRAD2, ANGV2 are included here in order to smooth the discontinuous function of the local uniform initial normal velocity distribution at two edge nodes by a continuous function (because in the finite-element model the compatibility

of v, w, ψ, and χ at boundary nodes of each element with neighboring elements is required).

If IOTB>0 in Card 17, the following No. 19 Card(s) must be included; otherwise, skip to Card 20.

Card 19

NODEV, VRAD, WRAD, ANGV — I5, 3D15.6

where

NODEV — The node number at which the initial generalized nodal velocity components are to be prescribed.

VRAD, WRAD, ANGV — The initial tangential velocity $\dot{v}_o$ (in/sec), normal velocity $\dot{w}_o$ (in/sec), and the angular velocity, $\dot{\psi}_o$ (rad/sec), respectively, which are to be prescribed on node NODEV.

Additional Card(s) 19A, 19B, ... are punched in the same format until the total number of cards specified equals IOTB in Card 16.

Card(s) 20, 20A, 20B ... are included only if IOTC>0 in Card 16.

Card 20

IS1, IS2, WRAD — 2I5,D15.6

where

IS1, IS2 — The first element and the number of elements over which the first local sine-shaped initial normal velocity distribution is to be prescribed.

WRAD — The peak value $\dot{w}_o$ (in/sec) of the first sine-shaped initial normal velocity distribution.

Card(s) 20A, 20B ... are punched in the same manner, until the total number of No. 20 cards equals IOTC on Card 17.

The remaining Cards (21 through 25 and 27) specify the amplitude, direction, and distribution of the subsequent time-dependent externally-applied forcing function.

Card 21

TBEGIN, TFINAL, AMP1FV, AMP1FW 4D15.6

where

TBEGIN, TFINAL	Times (seconds) which define the beginning and the end, respectively, of the complete externally-applied forcing function; i.e., the complete forcing function starts at TBEGIN and ends at TFINAL.
AMP1FV, AMP1FW	The circumferential and the normal components, respectively, of the normal force (amplitudes of the forcing function) (lbs) versus time history at time TBEGIN.

If there is no externally-applied forcing function during the run, set both TBEGIN and TFINAL equal to zero and leave AMP1FV, AMP1FW blank; if no forcing function is to be prescribed, go to Card 26.

Card 22

NOFT1, NOFT2, NOFT3 3I5

where

NOFT1	The number of concentrated loads which are to be prescribed (NOFT1$\le$4).
NOFT2	The number of local uniform load distributions which are to be prescribed (NOFT2$\le$4).
NOFT3	The number of local sine-shaped load distributions which are to be prescribed (NOFT3$\le$4).

Omit data group 23 if NOFT1=0 on Card 22.

Card 23

JELEM(1), ETA(1), RTOV(1), RTOW(1) I5,3D.15.6

where

JELEM(1), ETA(1)	The element number and the length coordinate along the reference axis from node JELEM(1), respectively, at which the first concentrated load is to be prescribed.

RTOV(1)
RTOW(1) — The normalized values of the first concentrated load with respect to the nominal forces in the circumferential and the normal directions, respectively, (lb/lb).

Card(s) 23A, 23B, ... are repeated in the same format, until the total number of No. 23 cards equals NOFT1 given in Card 22.

Skip data group Card(s) 24 to Card 25 if NOFT2=0 on Card 22.

Card 24

NSTF2(1), NELF2(1), RTO2V(1), RTO2W(1) 2I5,2D15.6

where

NSTF2(1)
NELF2(1) — The first element and the number of elements, respectively, over which the first local uniform load is to be distributed.

RTO2V(1)
RTO2W(1) — The normalized values of the first local uniform load distribution with respect to the nominal amplitudes in the circumferential and the normal directions, respectively, (lb-in/lb-in).

Card(s) 24A, 24B, ... are repeated in the same format until the total number of No. 24 cards equals NOFT2 on Card 22.

Card(s) 25 are included only if NOFT3>0; otherwise, skip to Card 26.

Card 25

NSTF3(1), NELF(3), RTO3V(1), RTO3W(1) 2I5,2D15.6

where

NSTF3(1)
NELF3(1) — The first element and the number of elements, respectively, over which the first local sine-shaped forcing function is to be distributed.

RTO3V(1)
RTO3W(1) — The normalized values of the fist local sine-shaped forcing function with respect to the nominal amplitudes in the circumferential and the normal directions, respectively (lb-in/lb-in).

Card(s) 25A, 25B, ... are repeated until the total number of No. 25 cards equals NOFT3 on Card 22.

Card 26

ICONT   I5

where

ICONT   Integer which if greater than 0 indicates that this is a continuation run. In order to use this option, it is necessary to obtain the following continuation cards from a previously-run job. To do this, set the variable MPU=1 at the beginning of the MAIN routine. This will cause the following set of data cards 26A through 26 NA to be punched. When using this deck, set ICONT=1 and use the same data cards as used before, except to change the values of MM and M1 on Card 1 and to modify Card 27.

If ICONT=0, skip Cards 26A-26NA and go to Card 27.

If the indicator ICONT is greater than zero, the continuation deck produced from the output of the previous run follows immediately. The continuation deck contains the following information:

Card 26A

IT, TIME, T1, T2   I5,3D20.13

where (L=1 for main structure; L=2, NBR+1 for branches):

IT   The number of the time cycle at which the previous run had stopped, and is the beginning time cycle of the present continuation run.

TIME   The absolute time at which the previous run stopped, and is the beginning time of the present continuation run.

T1, T2   Times at which the present linear segment of the force versus time curve starts and stops acting, respectively.

Card 26B

AMP1FV, AMP1FW, AMP2FV, AMP2FW   4D20.13

where

AMP1FV
AMP1FW
AMP2FV
AMP2FW

Nominal force amplitudes in the tangential and normal directions, respectively, at the beginning (1) and end (2) of the present linear segment of the force versus time curve.

Card 26C

SLOPEV, SLOPEW, APDEN, CINETO 4D20.13

where

SLOPEV
SLOPEW

Slopes of the piecewise linear segment approximation of the present nominal force versus time curve in the tangential and the normal direction, respectively.

APDEN Total work done on the structure by externally-applied forces up to the present time step.

CINETO Initial kinetic energy imparted to the structure.

Card 26D

IBIGA(L), ISTAA(L), BIGA(L), BTIMA(L), ISURA(L) 2I5,2D20.13,I5

where (L=1 for main structure; L=2, NBR+1 for branches):

IBIGA
ISTAA
BIGA
BTIMA
ISURA

Information for maximum "additional-point strain". Same as their counterparts on Card 26E.

Card 26E

IBIG(L), ISURF(L), ISTA(L), BIG(L), BTIME(L) 3I5,2D20.13

where (L=1 for main structure; L=2, NBR+1 for branches):

IBIG(L) The element number whose computed tensile strain exhibits the largest value during the previous run.

ISURF(L) Equals 1 means largest computed tensile strain occurs on the inner surface; equals 2 means on the outer surface.

ISTA(L) The Gaussian station at which the maximum strain occurred.

BIG(L) The largest computed tensile strain during the previous run.

BTIME(L) The time at which the largest computed tensile strain occurred during the previous run.

Card 26F

IBI(L), ISUR(L), BI(L), BTIM(L) 2I5,2D20.13

where (L=1 for main structure; L=2, NBR+1 for branches):

IBI(L)
ISUR(L)
BI(L)
BTIM(L)

Information for maximum average nodal point strain. Same as their counterparts on Card 26E.

CArd 26GA

DISP(I) 4D20.13

where

DISP(I) The displacement of the Ith degree of freedom at time cycle IT-1.

Card 26 HA

DELD(I) 4D20.13

where

DELD(I) The displacement increment change of the Ith degree-of-freedom of the structure at time cycle IT.

Card 26IA

DIS(I) 4D20.13

where

DIS(I) The displacement of the Ith degree of freedom at time cycle IT.

Card 26JA

DISM1(I) 4D20.13

where

DISM1(I) The displacement of the Ith degree of freedom at time cycle IT-2.

Card 26KA

FMECH(I) 4D20.13

where

FMECH(I) Assembled generalized load vector due to externally-applied forces at degree of freedom I.

Card 26LA

FLVA(I) 4D20.13

where

FLVA(I) Assembled generalized load vector due to large deflections and elastic plastic strains at each degree of freedom I.

*Note: Cards 26GA-26LA are individually repeated until information for each degree of freedom is included, with 4 different values/card.

Card 26MA

SNS(IR,J,K,L) 4D20.13

where

SNS(IR,J,K,L) The axial stress on the Lth mechanical sublayer at the Kth depthwise Gaussian point at the Jth spanwise Gaussian station of the IRth element at time cycle IT.

Card 26NA

SNP(IR,J,K,L) 4D20.13

where

SMP(IR,J,K,L) The total plastic strain of the Lth mechanical sublayer at the Kth depthwise Gaussian point at the Jth spanwise Gaussian station of the IRth element.

*Note: Cards 26MA and 26NA are both individually repeated until all values for the entire structure are included, with 4 different values/card.

Card 27

T2, AMP2FV, AMP2FW 3D15.6

where

T2 The time (seconds) of the second point to be specified on the normal force versus time curve.

AMP2FV, AMP2FW The nominal circumferential and normal force amplitudes, respectively, of the second point to be specified (lbs).

Cards 27A, 27B, ... have the same format as Card 27 and read successive values of T2, AMP2FV, and AMP2FW. T2, AMP2FV, and AMP2FW on each card give the coordinates of each succeeding point on the force versus time curve. There is no limit to the number of No. 27 cards that can be used when specifying the total forcing function by coordinates of the force versus time curve. However, it is important that the final No. 27 card specify the nominal force at a time which must be equal to or greater than TFINAL specified on Card 21; otherwise, computation will stop.

*Note: If ICONT≠0 on Card 26 and this is a continuation run, the only No. 27 cards to be included are those with a T2 greater than the starting time of this continuation run.

4.3 Input for Special Cases

While the JET 5A program is capable of analyzing the large-deformation, elastic-plastic response of a container/deflector structure, there will be instances when the user will wish to analyze only the elastic response of a material, or analyze the response of a membrane material. The JET 5A program is capable of performing these analyses with the following input and internal modifications.

4.3.1 Special Cases of the General Stress-Strain Relations

In the following the specific input data for three special cases of the general elastic, strain hardening constitutive relation handled by the computer program are given. Only the relevant data are noted. (L=1 for main structure; L=2 to NBR+1 for the NBR branches; M=1 to NLAY):

1. Purely Elastic Case

   Set NSFL(M,L)=1 on Card 2 and Card 9A, and make EPS(M,1,L) and SIG(M,1,L) on Card 4AA and Card 9AA sufficiently high so that no plastic deformation occurs; for example EPS(M,1,L)=1.0, SIG(M,1,L)= ES(M,1,L), where ES(M,1,L) equals the elastic (Young's) modulus.

2. Elastic, Perfectly-Plastic Case

   Set NSFL(M,L)=1 on Card 2 and Card 9A, and make EPS(M,1,L)=SIG(M,1,L)/ ES(M,1,L) on Card 4AA and Card 9AA.

3. Elastic, Linear Strain-Hardening Case

Set NSFL(M,L)=2 on Card 2 and Card 9A and set EPS(M,1,L)=SIG(M,J,L)/ES(M,1,L). Also EPS(M,2,L) and SIG(M,2,L) on Card 4AA and Card 9AA are taken sufficiently high in order to avoid plastic deformation in the second sublayer. For example, EPS(M,2,L)=1.0, and SIG(M,2,L)=(1.0-EPS(M,1,L))*ES(M,2,L)+SIG(M,1,L), where ES(M,2,L) is the slope of the segment in the plastic range.

4.3.2 Membrane Analysis

If the user wishes to analyze a membrane (a structure with no appreciable bending stiffness), there are five basic steps to be undertaken.

1. Set NFL = 1 on Card 1

2. Set TXG(1) = 0.0 on Card 13A

3. Set TWG(1) = 2.0 on Card 14A

4. Set NTERF = 0 on Card 10

5. This step requires an internal change to the MAIN program of JET 5A. At the appropriate locations in the MAIN program, during the strain calculations for printout, comment cards are present to instruct the user as to which terms should be changed or zeroed out. These changes eliminate the bending terms present in Eq. A.12.

4.4 Description of the Output

The printed output begins with a partial reiteration of the program input which identifies the problem being solved. This output includes information on: (1) initial geometry, (2) the nodal and element numbering system originally assigned by the user, (3) the new updated nodal and element system generated internally by the program if branches are present, (4) the branch attachment points, (5) the material properties for each layer of the main structure and for each branch, (6) the boundary conditions and elastic restraints as input, (7) the initial velocity locations and magnitudes, (8) the externally applied force locations, magnitude and timewise distribution, (9) the Gaussian stations and weights used in the program, (10) the assembled

mass and stiffness matrices, (11) the time step used in the program, and (12) an internally-calculated reference time step based on the maximum structural frequency. Illustrative outputs from example runs of JET 5A are listed in Section 7.

After the initial printout has been completed, the following information is printed out after cycle M1 has been completed, and at every M2 cycles thereafter (see Subsection 4.2, Card 1). In addition, for JET 5A runs, a printout is made before and after the first cycle to confirm the proper implementation of the user's designated initial velocity information.

```
CYCLE = [IT]
ELEMENT     SI  STA1  SO  SI  STA2  SO  SI  STA3  SO
   1
   2
   3
   .
   .
   .
cycle = [IT]
STRAIN AT ADDITIONAL POINTS           SI     SO     EI     EO
   1
   2
   .
   .
   .
J = [IT]      TIME = [TIME]
WORK INPUT INTO RING                          =  [CINETT]
RING KINETIC ENERGY                           =  [CINET]
RING ELASTIC ENERGY                           =  [ELAST]
RING PLASTIC WORK                             =  [PLAST]
ENERGY STORED IN ELASTIC RESTRAINTS           =  [SPDEN]
I   V   W   PSI   CHI   COPY   COPZ   L   M   STRAIN(IN)   STRAIN(OUT)
1
2
```

```
3
.
.
.
SUBSTRUCTURE       MSTR      ELE      TIME      STA
    1
    2
    .
    .
SUBSTRUCTURE       LARGEST ADD. PT. STRAIN      ELEM      ADD. PT.      TIME
    1
    2
    .
    .
SUBSTRUCTURE       LARGEST NODAL STRAIN         NODE      SURF          TIME
    1
    2
    .
    .
REACTIONS AT NODE      RV(LBS)      RW(LBS)      RM(IN-LBS)
         .                .            .             .
         .                .            .             .
         .                .            .             .
```

where

IT = Cycle number

TIME = Elapsed time corresponding to the <u>end</u> of cycle IT (sec.)

CINETT = Total work imparted to the structural ring up to the present time by the external loadings (in-lb).

CINET = The current value of kinetic energy present in the structural ring* (includes both the rigid body and the relative kinetic energies) (in-lb).

ELAST = Total elastic strain energy stored in the entire structural ring at the present time instant (in-lb).

PLAST = Total plastic work** done on the structural ring (mechanical work dissipated during plastic flow) (in-lb).

SPDEN = Total energy stored in the elastic-restoring springs and/or the elastic foundations at the current time instant (in-lb), if the presence of elastic restraints is specified.

SI = Strain γ_{11} (same as $\tilde{\varepsilon}$ of Eq. A.12) at the inner surface of the ring

SO = Strain γ_{11} at the outer surface of the ring

<u>Note</u>: If the strains at the interfaces of a multilayer structure are to be printed out, every other line will be strain at the inner and outer surface (starting with line one) and the second, fourth, sixth, etc. lines will be strains at interface one and two (going from the inner to

---

*It should be noted that the rigid body part of the kinetic energy, which is used to accelerate the "rigid body" mass of the structure, can be extracted and identified separately. However, for the present program dealing with rather general structural geometries and with various support/restraint conditions, it would be very unwieldy (but not impossible) to identify these separate kinetic energies; hence, the <u>total</u> kinetic energy is calculated and printed out.

**The plastic work done on the ring is <u>estimated</u> by subtracting the sum of the elastic and kinetic energies present in the ring from the total input energy (due to the externally-applied load and the initially-imparted kinetic energy); i.e., CINETT=CINET+ELAST+PLAST+SPDEN. It should be mentioned that the approximate nature of this numerical calculation will sometimes yield impossible results such as negative values of plastic work or values greater than zero when the ring has not yet reached a plastic condition; thus, the value of plastic work should be considered only approximate, and spurious results as noted above should be ignored.

the outer surface). If there is only one interface, the strain corresponding to the second interface will be the strain along the reference axis. This will be true for both strains at Gaussian stations and at additional strain points.

STA1, STA2, STA3 = Spanwise Gaussian Station at which strain was calculated.

EI, EO = Relative elongation at inner or outer surface, respectively, at the additional strain points; obtained from $E_1 = \sqrt{1+2\gamma_{11}} - 1$.

I = Node number. For a partial ring, the value of the total number of nodes equals the value of the total number of elements plus one. For a complete ring, the value of the total number of elements plus one. For a complete ring, the value of the total number of nodes equals the value of the total number of elements.

V = The middle plane axial displacement at node I (in).

W = The middle plane transverse displacement at node I (in).

PSI = The generalized nodal displacement $\psi = (\partial v/\partial \eta) - v/R$ at node I (rad).

CHI = The generalized nodal displacement $\chi = (\partial v/\partial \eta) + w/R$ at node I (rad).

COPY = The Y-location of node I in the global (inertial) coordinate system (in).

COPZ = The Z-location of node I in the global coordinate system (in).

L = Axial internal force resultant over the cross section at the midspan point of element I (lb).

M = Internal bending moment of the cross section at the midspan point of element I (lb).

STRAIN(IN) = Average strain on the inner surface at node I.*

STRAIN(OUT) = Average strain on the outer surface at node I.*

SUBSTRUCTURE = The portion of the ring being considered.

1 = main structure

2 = 1st branch

3 = 2nd branch

.

.

.

MSTR = Maximum strain on the substructure at a Gaussian station.

ELE = Element on which max. tension strain occurred.

TIME = Time at which max. tension strain occurred.

STA = Gaussian station at which max. tension strain occurred on element ELE.

NODE = Node at which largest average value of tension strain occurred.

ELEM = Element on which largest value of tension strain occurred at an additional strain point.

ADD. PT. = Additional Point Number.

TIME = Time at which the max. tension strain occurred.

REACTIONS AT NODE = The node number of a constrained node.

RV = The tangential reaction force (lbs).

RW = The normal reaction force (lbs).

RM = The reaction moment (in-lbs).

Note: Checks for largest average nodal strain and largest additional-point strain are made only at printout cycles. Check for largest Gaussian-station strain is made at each cycle.

---

*At nodes on the main structure where a branch connection occurs, the contribution of strain from the branch is not included in the nodal averaging process.

At the conclusion of the run, a final update of the maximum strain occurring on each substructure (main structure and each branch) and for the additional strain points on the main structure and each branch is printed out. Also, a note as to whether or not continuation cards were punched is made.

4.5 Guidelines and Restrictions for Code Usage

4.5.1 General Instructions

The JET 5A computer code is capable of handling a wide variety of transient, large-deflection structural response problems involving external loadings. This capability is beneficial to the user since it is contained in one computer program; however, it can be unnecessarily costly to run the program if all of the options included are carried along but are not being used.

In order to save storage locations and, therefore, save computer costs on each run, several subroutines can be removed when they are not used during that particular job submittal.

The following is a list of subroutines which must be included in every run of the JET 5A program:

MAIN	FAC	PRINT
ASSEF	IDNT	SOLV
ASSEM	IMPULS	STRESS
ELMPP	MINV	
ERC	OMULT	

The remaining subroutines: BRAN, LOADEQ, LOADFT, QREM, ROTAT, and TSTEP may be left out depending upon the type of problem being solved.

Subroutine TSTEP may be optional when the user desires (i.e. when the user does not specify DELTAT = 0.0 on Card 5). The user merely has to omit the TSTEP subroutine, and only inputs the following three cards instead of TSTEP:

```
SUBROUTINE   TSTEP   (AMASS, STIFK, DELTAT)
RETURN
END
```

In like manner, if the user does not wish to apply any branches to the

main structure, the BRAN subroutine becomes optional. If no branches are used, BRAN is input as follows:

```
SUBROUTINE BRAN (NBR)
RETURN
END
```

Thus, for any subroutine that is not being used for a particular run, just submit the first card of the subroutine (the name card) and the RETURN and END cards. This will save the user input costs, compilation costs, and storage costs. The same procedure is used for QREM if no elastic restraints are defined, for ROTAT if no branches or slope discontinuities are used, and for LOADEQ and LOADFT if no external forcing functions are specified.

Finally, it should be noted that if the various layers of the multi-layer structure consist of the same material and if a branch is attached and consists of a different material, unreliable results can be expected because the present element assembly logic does not accommodate this situation properly.

4.5.2 Comments on Strain Calculations

In the present JET 5A program, options are available which allow the user to obtain strain printout at the spanwise Gaussian stations (which include the element midspan location), and/or at additional points on the structure specified by the user. Nodal average strains are given automatically at each regular printout cycle. This flexibility can be of great value to the user, but certain precautions should be taken by the user in interpreting the strain results.

The strain-displacement relation employed in the present curved beam elements is given by Eq. A.12. An examination of this equation shows that nonlinear terms are included only in the membrane behavior, and only linear terms are included in the bending behavior. Thus, the membrane nonlinearities have been assumed to be more significant than the bending nonlinearities. The calculated distribution of strain may be quite different from element to element, and the strain distribution within each element will, in general, not be the same as the "exact" distribution. This behavior corresponds to the fact that in the present finite-element model the predicted strain distribution

approximates the actual strain distribution in an average (integral) sense, and not in a pointwise sense. Although the calculated distribution may be the same as the "exact" distribution at some points within the element, the choice of a "best"point (or points) for strain evaluation within an element is not obvious. The choice of v, w, ψ, and χ as generalized nodal parameters assures membrane strain continuity at the nodes, but in general the bending strain will not be continuous at the nodes; thus, the predicted strains at the inner and outer surface of an element will not, in general, be continuous at the nodes.

Because of these facts, certain precautions should be taken by the user when assessing strain distributions in space and/or time. If detailed strain distributions are required over a portion of the structure at a particular time instant, it is suggested that several printout points be chosen in each element (e.g. Gaussian stations and nodal averaged points) in the region of interest. When these calculated values are plotted, the analyst can then make a reasonable "faired" estimate of the "proper" distribution. It should be noted that severe strain gradients within an element do not necessarily indicate poor behavior of the solution; however, it is in these regions where the analyst must exercise the greatest caution in making a reasonable faired estimate of the proper distribution. Although not conclusive, experience to date with the present JET 5A computer code suggests that these regions of predicted severe strain gradients are most often observed near clamped boundaries.

If strain time-history information is required at various points on the structure, these points can be specified as additional strain points and the time histories may be obtained directly. In addition, it is recommended that spatial distributions near these points of interest be obtained at several time instants to assess whether or not the strain at the point of interest is in reasonable agreement with the curve-fitted (or faired) distribution in that region of the structure. If these steps are followed, a reasonable engineering assessment of strain information should be obtained.

The equations in Appendix A have been developed within the assumption of large deflections but small strains. Thus, reliable results may not be obtained in localized regions where large strains are predicted. However, the actual strain level at which the "small strain" assumption becomes invalid is

not known. Thus, the limitations of the present analysis, for practical engineering problems, cannot be clearly stated; further study of the limitations of the present analysis versus appropriate well-defined experimental data is required. In the future it is recommended that models which can accommodate arbitrarily large strain be developed for both two-dimensional (planar) and three-dimensional (non-planar) deformations. In the meantime, however, it is believed that the capabilities of the present JET 5A analysis and program can provide useful engineering estimates.

4.5.3 Comments on Code Use on Other Computer Systems

The JET 5A computer code has been exercised largely on an IBM 370/168 computer system at the MIT Information Processing Center with MIT's version of IBM's G compiler (including all updated IBM modifications). The example problem results given in Subsection 7.1.3 were obtained from this system.

Each user will need to assess what kind of computer code statement changes need to be made (if any) to the FORTRAN IV source code given in this report in order to adapt the code to his particular computer facility. The user should be aware of the fact that the use of different compilers at a given computer facility can produce somewhat different transient response predictions. For example, the use of a TSS compiler with an IBM 360 system at the NASA Lewis Research Center led to slightly different transient strain predictions and significantly different support reactions than given in the solution results of Subsections 7.1.3 and 7.2.3 (for CIVM-JET 5B) with code modifications included to adapt to that NASA system. However, subsequently, the "modified adapted" code was used on that IBM 360 system with NASA's H-extended compiler; the results agreed exactly with those given in the present report. For the two example problems (see Subsections 7.1 and 7.2), some results obtained with several computing systems and compilers at NASA-Lewis and MIT are given in the table on page 297.

SECTION 5

USE OF THE CIVM-JET 5B PROGRAM

The CIVM-JET 5B program has been designed to be as similar to the JET 5A program as possible. This will aid the user in adapting from one program to the other. The user is encouraged to read Section 4 before using Section 5, because this section depends on information already covered in Section 4. Subsections 4.1 and 4.4 hold equally well for both JET 5A and CIVM-JET 5B and are not repeated in this section.

5.1 Input Information and Procedure

The input information required for CIVM-JET 5B is very similar to that just described in Subsection 4.2 for JET 5A, except for some slight modifications. The data cards are listed in the following. To avoid needless repetition, only variables which newly appear and/or have different definitions are described.

	FORMAT
Card 1	
IK, ICP, NLAY, LREF, NOGA, NFL, MM, M1, M2, ICON	10I5
Card 2	
NSFL(1,1) .... NSFL(NLAY, 1)	3I5
Card 3A	
DENS(1,1), DS(1,1), P(1,1)	3D15.6
Card 4AA	
EPS(1,1,1), SIG(1,1,1), EPS(1,2,1), SIG(1,2,1)	4D15.6

Additional Cards 4AB and 4AC are punched in exactly the same manner as Card 4AA until the number of coordinate pairs equals NSFL(1,1) punched on Card 2 for layer 1. The total number of coordinate pairs must not exceed 5 for any layer. Do not include any unneeded (blank) cards.

Cards 3 through 4 are repeated for each additional layer in the multilayer ring until the number of sets of cards equals NLAY (given on Card 1). The total number of card sets must not exceed 3.

Card 5

B(1), DELTAT 2D15.6

Card 5A

Y(1), Z(1), ANG(1) 3D15.6

Additional Cards 6B, 6C ... are punched in exactly the same format as Card 6A until the total number of No. 6 cards equals (IK+1) for a partial ring and equals IK for a complete ring, where IK is the value appearing on Card 1. See Card 6A, Subsection 4.2, for further restrictions.

Card 7A

H(1,1), ... H(1, NLAY), H(2,1)... 5D15.6

Card(s) 7B, 7C, ... are repeated in the same format until the thicknesses of each layer of the ring at every nodal station are defined. The total number of data on Cards 7 (with 5 data on each card) should be equal to NLAY*IK for a complete ring and equal to NLAY*(IK+1) for a partial ring.

Card 8A

NDIS I5

If there are no slope discontinuities on the main structure, set NDIS=0 and go to Card 9.

Card 8BA

NEDI(I), ANGDI(I) 4(I5,D15.6)

Additional Cards 8BB, 8BC, etc. are used until all of the "slope discontinuities" are described. See Fig. 10 for a further description of the discontinuity option.

The sequence of cards starting with Card 9 and going through Card 9DB contains all the data for the single layer branches to be applied to the main structure except that elastic restraints must be handled as one unit on Card 16. See Subsection 4.2 for a complete explanation of the branch option.

Card 9

NBR I5

If NBR=0 Go to Card 10.

Card 9A

NSFL(1,L), B(L), DENS(1,L), DS(1,L), P(1,L) I5, 4D15.6

Card 9AA

EPS(1,J,L), SIG(1,J,L) 4D15.6

Additional Cards 9AB and 9AC are punched in exactly the same manner as Card 9AA until the number of coordinate pairs equals NSFL(1,L) punched on Card 9A. Do not include any unneeded (blank) cards.

Card 9B

NELT(I), NODP(I), LHIT(I), LATT(I) 4I5

where

I — Number of branch I=1, NBR

LHIT(I) — Determines whether or not branch can be impacted:

- LHIT(I)=0 No impact
- LHIT(I)=1 Impact

Note: While it may be useful to allow branches to be impacted at some future time, at present branch impact is not allowed. Set LHIT(I)=0 for all CIVM-JET 5B computer runs.

LATT(I) — Determines where branch is to be attached.

- LATT(I)= -1 inner surface
- 0 outer surface
- 1, 2, 3 midsurface of respective layer.

Card 9BA

YB(I,J), ZB(I,J), ANB(I,J), HB(I,J) 4D15.6

where

I = branch number, J = node number

See Subsection 4.2 for further restrictions.

Cards 9BB, 9BC, etc., are punched until (NELT+1) nodes have been described.

Card 9C

NDlSB I5

If there are no discontinuities on the branches, set NDISB=0 and go to Card 9D.

Card 9CA

NEDIB, NBDI, ANGB 2I5,D15.6

Cards 9CB, 9CC, etc., follow until the information for all NDISB branch slope-discontinuities has been given.

Card 9D

NBCONB I5

If NBCONB=0 go to Card 10.

Card 9DA

NBCB(I), NODBB(I), LBR(I) 4(3I5)

where

I=1, NBCONB

See Subsection 4.2 for further remarks about the branch input.

Card 10

NOP, NASP, NTERF 3I5

If NOP $\neq$ 2 or 3, go to Card 11.

Card 10A

NSBS(I), NSEL(I), AZET(I) 2I5,D15.6

where

I=1, NASP

Cards 10B, 10C, etc. are used until all the additional strain points have been described.

Card 11

AXG(1), AXG(2), AXG(3) 3D25.16

Card 12

AWG(1), AWG(2), AWG(3) 3D25.16

Card 13A

TXG(1), TXG(2), TXG(3) 3D25.16

Card 13B

TXG(4) 3D25.16

Card 14A

TWG(1), TWG(2), TWG(3) 3D25.16

Card 14B

TWG(4) 3D25.16

See Subsection 4.2 for further instructions.

Card 15

NBCOND, NBC(1), NODEB(1), NBC(2), NODEB(2), ... NBC(7), NODEB(7) 9I5

See Subsection 4.2 for a full explanation of the above boundary conditions.

Card 16

NQR, NORP, NORU 3I5

If NQR=0 go to Card 17.
If NORP=0, Skip to Card 16B

Card 16A

SCTP, SCTY, SCRP 3D15.6

Card 16AA

NREL(1), REX(1), NREC(2), REX(2), ... NREL(4), REX(4) 4(I5,D15.6)

If NORU=0 in Card 16, omit Card 16B, and Card 17 follows directly.

Card 16B

SCTU, SCTW, SCRU 3D15.6

Card 16BB

NRST(1), NREU(1), ... NRST(4), NREU(4) 8I5

Cards 17 and 18 contain the input data concerning the attacking fragment(s).

Card 17

NF, EFLN(1) I5,D15.6

where

NF — The number of fragments considered to be impacting the structure. This number cannot exceed 3.

EFLN(1) — The "effective length" of the impact-affected zone. The user can select an "appropriate" value for this quantity; or, if EFLN(1)=0, the program will choose a value for EFLN(1) given by EFLN(1) = $\Delta t\sqrt{E/\rho}$ where E = Young's modulus and ρ = the mass density of a layer. The largest EFLN(1) calculated for each layer, will be the "effective length" employed for the entire structure.

Card 18AA

FH(I), FCG(I), FCGX(I), FMASS(I), FMOI(I) — 5D15.6

Card 18AB

UNK(I) — D15.6

Card 18AC

UDOT(I), WDOT(I), ADOT(I), TPRIM(I), CR(I) — 5D15.6

where I = number of fragment. $I \leq 3$

FH(I) — The diameter of the circular disk model of the Ith fragment (inches).

FCG(I) — The Z coordinate of the centroid of the Ith fragment before and at the time of its release. The positive direction represents a location above the global Y axis (inches).

FCGX(I) — The Y coordinate of the centroid of the Ith fragment before and at the time of its release. The positive direction represents a location to the right of the global Z axis (inches).

FMASS(I) — The mass of the Ith fragment ($lb\text{-}sec^2/in$).

FMOI(I) — The mass moment of inertia of the Ith fragment ($lb\text{-}sec^2\text{-}in$).

UNK(I) — Coefficient of friction between the Ith fragment and the ring inner surface.

UDOT(I) The velocity component of the Ith fragment parallel to the global Y axis before initial impact (in/sec). Positive UDOT(I) represents a fragment traveling to the right.

WDOT(I) The velocity component of the Ith fragment parallel to the global Z axis before initial impact. The positive direction denotes a fragment traveling in an upward (+Z) direction (in/sec).

ADOT(I) The initial angular velocity of the Ith fragment (rad/sec). Positive sign denotes counterclockwise rotation.

TPRIM(I) Time (seconds) that the fragment is allowed to travel before program starts to track its location. One usage of TPRIM(I) allows fragments to be relased after the first fragment has impacted and calculations have begun.

The fragments should be ordered as follows to allow proper use of the TPRIM capability: Fragment 1 should be the fragment that will make first contact with the ring. Time zero is the time of release of this fragment. The second group of fragments includes all of the fragments that will be released before the first fragment impacts. The fragments can be placed in any order within their group. The third group contains those fragments released after the first fragment impacts; these must be ordered such that the first fragment to be released is first and so on within this group. TPRIM(1) = Time of impact of first fragment minus time of release. Since time of release of fragment one is equal to 0, TPRIM(1) equals time of first impact. Actually, TPRIM(1) must be less than the time of first impact to guarantee a proper impact solution.

TPRIM(I) where I = 2, NF equals TPRIM(1) minus time of release of the Ith fragment. Thus, TPRIM, for those fragments released after the first fragment impacts, will be negative. TPRIM(I) must be a multiple of the Δt used.

CR(I) Coefficient of restitution between the Ith fragment and the impacted ring inner surface ($0 \leq CR \leq 1$); equals 1 for perfectly elastic, 0 for perfectly inelastic, $0<CR<1$ for intermediate. CR=1 is usually recommended.

Cards 18BA, 18BB, 18BC, 18CA, 18CB, 18CC, ... should follow (in blocks of three cards) until the information for all NF fragments has been completely specified.

Card 19

ICONT	I5

where

ICONT Integer which if greater than 0 indicates that this is a continuation run. In order to use this option, it is necessary to obtain the following continuation cards from a previously run job. To do this, set the variable MPU=1 at the beginning of the MAIN routine. This will cause the following set of data cards 19A through 19NA to be punched. When using this deck, set ICONT=1 and <u>use the same data cards as used before</u>, except to change the values of MM and M1 on Card 1.

If ICONT=0, skip Cards 19A-19NA. If the indicator ICONT is greater than zero, the continuation deck produced from the output of the previous run follows immediately. The continuation deck contains the following information:

Card 19A

IT, TIME, IMOU, TAII	2(I5,D20.13)

where

IMOU The number of impacts up to the end of the last run.

TAII Time of initial impact.

CArd 19BA

IBIGA(L), ISTAA(L), BIGA(L), BTIMA(L), ISURA(L)	2I5,2D20.13,I5

Card 19CA

IBIG(L), ISURF(L), ISTA(L), BIG(L), BTIME(L)	3I5,2D20.13

Card 19DA

IBI(L), ISUR(L), BI(L), BTIM(L) 2I5,2D20.13

Card 19E

MIRP, TNJ(1), ... , TNJ(NF) I5,3D20.13

where

NF	Number of fragments impacting structure.
MIRP	Number of next fragment waiting to be released.
TNJ(J)	Indicates whether or not the Jth fragment has been released:

TNJ(J)=0.0	not released
TNJ(J)=1.0	released

Card 19FA

DISP(I) 4D20.13

Card 19GA

DELD(I)

Card 19HA

DELDM1(I) 4D20.13

Card 19IA

FLVA(I) 4D20.13

Card 19JA

QVEL(I) 4D20.13

where

QVEL(I) The velocity at the present instant of time for the Ith degree of freedom.

Card 19KA

QACL(I) 4D20.13

where

QACL(I) The acceleration at the present instant of time for the Ith degree of freedom.

Card 19MA

SNP(IR,J,K,L) 4D20.13

Card 19NA

FCGU(J), FCGW(J), ALFA(J), UDOT(J), WDOT(J), ADOT(J) 4D20.13

where

FCGU(J) The centroidal position of the Jth fragment in the Y direction at time cycle IT (inches).

FCGW(J) The centroidal position of the Jth fragment in the Z direction at time cycle IT (inches).

ALFA(J) The total angular displacement of the Jth fragment at time cycle IT (radians).

UDOT(J)
WDOT(J)
ADOT(J)
J=1, NF

Fragment velocities at time cyle IT (in/sec); see Card 18AC for more details.

5.2 Description of the Output

The output for CIVM-JET 5B is exactly the same as the output generated by the JET 5A program (described in Subsection 4.4), except for two places where data are given for the attacking fragments.

After each printout cycle (designated by the user on Card 1), an update of the fragments locations and velocities is given as follows:

FRAG NO.	FCGU	FCGW	ALFA	FRUV	FRWV	FRAV
1						
2						
.						
.						
.						

where

FCGU = Global Y coordinate of the centroid of the fragment at the current time instant (in).

FCGW	= Global Z coordinate of the centroid of the fragment at the current time instant (in).
ALFA	= Angular rotation of the fragment to the current time instant (rad).
FRUV	= The current velocity component of the fragment in the Y direction (in/sec).
FRWV	= The current velocity component of the fragment in the Z direction (in/sec).
FRAV	= The current angular velocity of the fragment (rad/sec). Positive sign denotes couter-clockwise rotation.

In addition to the above information, whenever there is an impact, the following information is printed out:

IMPACT NO.	TIME =	DURING CYCLE =	ELEM =
FRAG =	DISTANCE =		
FRAG[J]	TE =	RE =	TOE =

where

DISTANCE	The ratio of the distance from the first node of the element to the point of impact divided by the straight line distance from node 1 to node 2.
J	The J'th fragment
TE	Translational kinetic energy of fragment J immediately following the impact.
RE	Rotational kinetic energy of fragment J immediately following the impact.
TOE	Total kinetic energy of fragment J immediately following the impact. TOE=TE+RE.

5.3 Guidelines and Restrictions for Code Usage*

5.3.1 General Instructions

The following is a list of subroutines which must be included in every run of the CIVM-JET 5B program:

*The remarks given in Subsection 4.5.3 concerning use of JET 5A on various computer systems apply also to CIVM-JET 5B.

ASSEF	FAC	MAIN	PRINT
ASSEM	IDNT	MINV	SOLV
ELMPP	IMPACT	OMULT	STRESS
ERC	IMPCTE	PENTRN	

The remaining subroutines: BRAN, QREM, ROTAT, and TSTEP may be left out depending upon the type of problem being solved. See Subsection 4.5.1 for a detailed explanation.

5.3.2 Use of Branches vs. Use of Discontinuities

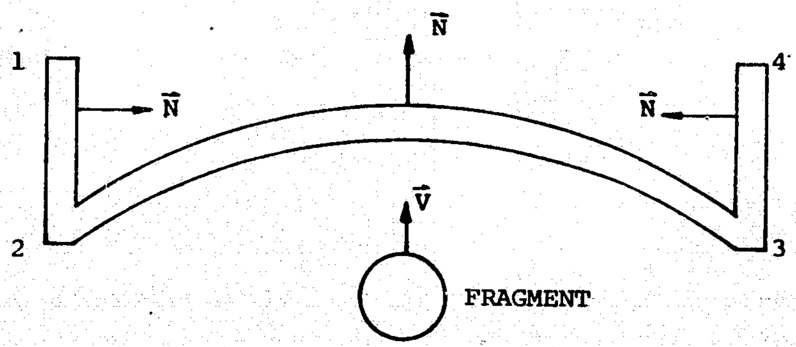
In the present CIVM-JET 5B program, both branches attached to and slope-discontinuities in the main structure can be accommodated. Because of the way in which these two features are handled in the program logic and, in particular, for determining ring-fragment collision, certain general guidelines should be followed by the user for more efficient use of the computer code.

The dominant consideration involves the determination of ring-fragment collision. In the present code, impact on a branch is not accommodated, so that if branch impact is an important consideration for a particular problem, then the slope-discontinuity option must be used in place of the branch option, thus, identifying this region not as a branch but as a part of the main structure. Note, however, that in all cases where three elements are to be connected at a single nodal point (such as in the case of a branch at the midspan of a beam), one of the elements must be defined as a branch. In general, at any node where three elements are joined, one of these elements (and all subsequent elements in that portion of the structure) must be defined as branch elements. However, two branches may not start at the same node of the main structure.

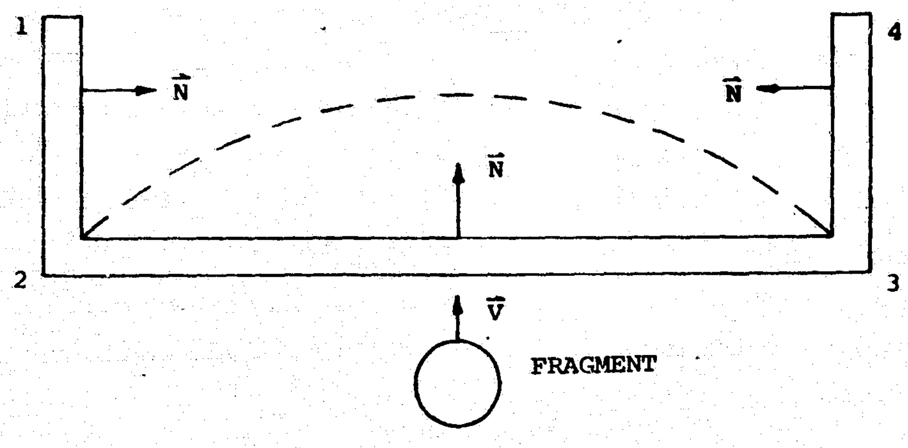
During each increment in time, Δt, a collision inspection is carried out for each element on the main structure for each of the N fragments considered, but no collision inspection is carried out for elements defined as branch elements. This fact can be used to reduce the total computation time; if the user knows a priori that no collisions will occur in certain regions of the structure, then those regions should be defined as branches wherever possible (note that branches cannot be specified to be attached to another branch).

It should be noted that complete nodal generalized displacement compatibility at a junction between a branch and the main structure is contained in the program logic regardless of whether the main structure and the branch are composed of the same or different materials. In the latter case this leads to results at and near the junction which are somewhat inconsistent physically; improved results could be expected if one were to require nodal compatibility only for v, w, and ψ (rather than for v, w, ψ, and χ where $\chi = \frac{\partial v}{\partial \eta} + \frac{w}{R}$).

As noted in Section 2, the positive η direction must be chosen in such a way that the outward normal for each element is directed toward the outside of the structure, where the fragments are considered to be in the inside of the structure. In some special (but plausible) cases, the outside region of a portion of the structure may overlap with the inside region of another portion of the structure either in the initial structural configuration or after some deformation of the structure has occurred. Within the current collision inspection program logic, such overlapping regions cannot be accommodated. Consider the following initial structural configuration:



With the positive normal directions $\bar{N}$ as shown (and considering the entire structure as a main structure, using the slope-discontinuity option), the outside regions of segments 1-2 and 3-4 would overlap with the inside region of segment 2-3. To accommodate such a configuration, segments 1-2 and 3-4 must be defined as branches so that no collision inspection is performed for those segments. Consider now the following initial structural configuration:



For the <u>initial</u> configuration (solid lines), no inside-outside overlapping occurs. However, after deformation of segment 2-3 (dashed line, assuming fragment impact is as depicted above), the outside regions of segments 1-2 and 3-4 will overlap with the inside region of segment 2-3. Again, in this case, segments 1-2 and 3-4 must be defined as branches.

5.3.3 Impact at or Near a Constrained Node

In the present CIVM-JET 5B program, the case of fragment impact on or near a constrained node is handled in an approximate fashion. The nature of this approximation is discussed briefly here as a guide to the user in interpreting results when impact occurs on or near a constrained node.

The assumption used is as follows: when impact occurs near a constrained node, the only nodes which can respond with impact-induced velocity changes are those nodes which lie within the impact-affected region and which are located on the impacted side of the constrained node. In essence, no impact-induced information is allowed to propagate past the constrained node (for the purpose of impact corrections), and a portion of the impact-induced impulse is "absorbed" by the constraint. Although no impact-induced information is allowed to propagate past the constrained node for the purpose of impact-induced velocity, the impact-induced information will filter through the constrained node in the global timewise solution if the constrained node is smoothly hinged.

If the node is ideally clamped, no impact-induced information will filter past the constrained node in the global timewise solution. It should also be noted that as the point of ring-fragment impact approaches the constrained node, the impact-induced ring response approaches zero; when impact occurs directly on a constrained node, the fragment simply rebounds and no impact-induced structural response occurs.

For a more thorough discussion of this topic, the reader is referred to Appendix B.

5.3.4 Comments on Space Mesh Sizing

In the present CIVM-JET 5B program, considerable flexibility is given to the user in terms of defining the size and number of elements to be used for a particular structural geometry. However, certain guidelines should be followed in the selection of a finite-element mesh for the present impact analysis. It is recommended that a uniform mesh be employed for all analyses, the only exception being in regions where structural detail dictates the use of nonuniform elements. Clearly this recommendation is justified for the general case where the point of initial (and subsequent) impact is not known a priori. Now consider the special (limiting) case where it is known a priori that all ring-fragment impacts will occur at (approximately) the same point on the structure (e.g. initially straight, uniform thickness, doubly clamped beam with the only nonzero component of the fragment velocity being normal to the beam midsurface, and initial impact occurring at the midspan of the beam). A uniform mesh is again recommended for this special case, based on the following considerations. One estimate* of the impact-affected length, L_{eff}, is $L_{eff} = \sqrt{\frac{E}{\rho}}\,\Delta t$; when using the central difference operator, the allowable time step, Δt, is inversely related to the highest natural frequency, ω_{max}, of the assembled structure. If the element size in the region of impact is decreased, then ω_{max} is increased and Δt and, thus, L_{eff} are decreased. In the limit, as the element size is decreased, the impact-induced "loading" will become concentrated at the point of impact and unreasonably high strain predictions may be found near this region of concentrated loading. It is believed (based on experience to date with the present CIVM-JET 5B program) that the choice of a uniform mesh for this case will yield the most reliable predictions.

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*Basically, however, L_{eff}, must be independent of Δt since various Δt sizes are permissible with different finite-difference time operators. From considerations of through-the-thickness stress wave propagation and accompanying imparted particle velocities, one might estimate $L_{eff} \doteq nh$ where h is the total wall thickness and n is some number typically $2 \lesssim n \lesssim 4$.

SECTION 6

COMPLETE FORTRAN IV LISTINGS OF THE PROGRAMS

6.1 Subroutines Common to both JET 5A and CIVM-JET 5B

These fourteen (14) subroutines consist of:

ASSEF	MINV
ASSEM	ØMULT
BRAN	QREM
ELMPP	RØTAT
ERC	SØLV
FAC	STRESS
IDENT	TSTEP

and are listed in the following:

```
      SUBROUTINE ASSEF(IR,IK,ELFP,FLVA,ICP)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION NN(8),FLVA(1),ELFP(1)
     COMMON /BR/ NVEC(51,2), LMT(51)
     J1 = NVEC(IR,1)*4
      NN(1)=J1-3
      NN(2)=J1-2
      NN(3)=J1-1
      NN(4)=J1
      IF(ICP.LE.0) GO TO 121
      IF(IR-IK) 121,122,122
 121 J2 = NVEC(IR,2)*4
      NN(5)=J2-3
      NN(6)=J2-2
      NN(7)=J2-1
      NN(8)=J2
      GO TO 123
122   NN(5)=1
      NN(6)=2
      NN(7)=3
      NN(8)=4
123   DO 101 I=1,8
      M=NN(I)
      FLVA(M)=FLVA(M)+ELFP(I)
101   CONTINUE
      RETURN
     END
```

```
      SUBROUTINE ASSEM(IR,IK,ELMAS,STIFM,ICP,INUM)                      ASSM0010
      IMPLICIT REAL*8(A-H,O-Z)                                          ASSM0020
      DIMENSION ELMAS(8,8),NN(8),STIFM(1),INUM(1)                       ASSM0030
     CCMMON /BR/ NVEC(51,2), LMT(51)                                    ASSM0040
     J1 = NVEC(IR,1)*4                                                  ASSM0050
      NN(1)=J1-3                                                        ASSM0060
      NN(2)=J1-2                                                        ASSM0070
      NN(3)=J1-1                                                        ASSM0080
      NN(4)=J1                                                          ASSM0090
      IF(ICP. LE.0) GO TO 203                                           ASSM0100
      IF(IR-IK) 203,204,204                                             ASSM0110
 203 J2 = NVEC(IR,2)*4                                                  ASSM0120
      NN(5)=J2-3                                                        ASSM0130
      NN(6)=J2-2                                                        ASSM0140
      NN(7)=J2-1                                                        ASSM0150
      NN(8)=J2                                                          ASSM0160
      GO TO 202                                                         ASSM0170
 204  NN(5)=1                                                           ASSM0180
      NN(6)=2                                                           ASSM0190
      NN(7)=3                                                           ASSM0200
      NN(8)=4                                                           ASSM0210
 202  DO 402 I=1,8                                                      ASSM0220
      M=NN(I)                                                           ASSM0230
      DO 402 J=1,8                                                      ASSM0240
      N=NN(J)                                                           ASSM0250
      IF(M-N)402,403,403                                                ASSM0260
 403  L=N+INUM(M)                                                       ASSM0270
      STIFM(L)=STIFM(L)+ELMAS(I,J)                                      ASSM0280
 402  CONTINUE                                                          ASSM0290
      RETURN                                                            ASSM0300
     END                                                                ASSM0310
```

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C-2

```
      SUBROUTINE BRAN(NBR,DENS,EPS,SIG,B)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION  SLB(5)
      DIMENSION DENS(3,6),B(6),EPS(3,5,6),SIG(3,5,6)
      DIMENSION LBR(7),ZK(51),HK(51,3),ANGK(51),LATT(6),LHIT(6)
      DIMENSION YB(5,11),ZB(5,11),ANB(5,11),HB(5,11),NELT(6)
      COMMON /FG/ IK,IKK,ICP,LREF,NOGA,NFL,NI,ICOL(205),INUM(205)
     *,NBCOND,NBC(7),NODEB(7),KROW(8),NDEX(8),NIRREG
      COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      COMMON /THI/ HTH(5)
      COMMON/MAT/YOUNG(3,6),DS(3,6),SNO(3,5,6),NSPL(3,6),P(3,6),NLAY
      COMMON/FC/ Y(51),Z(51),ANG(51),H(51,3)
      COMMON/BOUN/YK(51),NBCONB,NBCB(7),NODBB(7),MK(51),ROT(5,2)
     *,XDIST(6),DROT(50),NODP(6)
      COMMON /ML/ MNEL(6) ,MATT(6)
      COMMON/DIS/ ANGDI(50),NEDI(50),NDIS
      COMMON /BR/ NVEC(51,2), LMT(51)
      COMMON /TAM/ MKE(51)
C     RENUMBER NODES AND ELEMENTS
      EXANG= 360.0
      IF(ICP.LE.0) EXANG= 0.0
      NS = IKK
      NNS = NS
      NIK = IK
      PIE= 3.141592653589793D+00
      DO 5301 J= 1,6
      NELT(J) = 0
 5301 NODP(J) = 0
      DO 5302 K = 1,NS
      YK(K)= Y(K)
      ZK(K) = Z(K)
      DO 5303 L=1,NLAY
 5303 HK(K,L) = H(K,L)
 5302 ANGK(K)= ANG(K)
      DO 5313 I = 1,NBR
      IB = I+1
```


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```
      READ(MREAD,5500) NSFL(1,IB),B(IB),DENS(1,IB),DS(1,IB),P(1,IB)
 5500 FORMAT(I5,4D15.6)
      L= NSFL(1,IB)
      READ(MREAD,5510)   (EPS(1,J,IB),SIG(1,J,IB),J=1,L)
 5510 FORMAT(4D15.6)
      READ  (MREAD,5300) NELT(I),NODP(I),LHIT(I),LATT(I)
 5300 FORMAT(14I5)
      MNEL(I+1) = NELT(I)
      NODPH= NODP(I)
      IF  (LATT(I)) 6010,6015,6020
 6010 IF  (LREF-2)   6011,6012,6013
 6011 XDIST(I)= +H(NODPH,1)/2.0
      GOTO 6001
 6012 XDIST(I)=    (H(NODPH,1)+H(NODPH,2)/2.0 )
      GOTO 6001
 6013 XDIST(I)=    (H(NODPH,1)+H(NODPH,2)+H(NODPH,3)/2.0)
      GOTO 6001
 6015 IF(LREF-2) 6016,6017,6018
 6016 XDIST(I)=-(H(NODPH,1)/2.0 + H(NODPH,2)  + H(NODPH,3))
      GOTO 6001
 6017 XDIST(I)=-( H(NODPH,2)  /2.0 + H(NODPH,3))
      GOTO 6001
 6018 XDIST(I)  =-H(NODPH,3)   /2.0
      GOTO 6001
 6020 IF(LREF.NE.LATT(I)) GO TO 6025
      XDIST(I)   =  0.0
      GOTO 6001
 6025 LRA=  LATT(I) -LREF
      LSIGN=-1
      IF  (LRA.LT.0) LSIGN=  1
      LRAA  =  IABS(LRA)
      NNNN= LATT(I)
       IF(LRAA.EQ.2) GO TO 6030
      XDIST(I)=((H(NODPH,LREF)+H(NODPH,NNNN))/2.0)*LSIGN
      GOTO 6001
 6030 XDIST(I)=((H(NODPH,LREF)+H(NODPH,NNNN))/2.0+H(NODPH,LRAA))*LSIGN
```

```
6001 CONTINUE
     NO1 = NELT(I) + 1
     DO 5310 J = 1,NO1
     READ(MREAD,5305) YB(I,J),ZB(I,J),ANB(I,J),HB(I,J)
5305 FORMAT(4D15.6)
     ANB(I,J) = ANB(I,J)*PIE/180.0
5310 CONTINUE
     HTH(I) = HB(I,NO1)
     SLB(I) = ANB(I,NO1)
     NS=NS+NELT(I)
     IK= IK+NELT(I)
     IKK= NS
5313 CONTINUE
     DO 5200 K=1,NS
     MK(K) = 0
5200 LMT(K)= 0
      DO 5270 I=NIK,IK
5270 MKE(I) = 1
     WRITE(MWRITE,5311) IK,NS
5311 FORMAT('0THERE ARE ',I3,' ELEMENTS AND ',I3,' NODES')
     WRITE(MWRITE,5312) NBR,(NODP(M),M=1,NBR)
5312 FORMAT('0THERE ARE ',I3,' BRANCHES AND THEY ARE AT NODES',5I6)
     WRITE(MWRITE, 8500) (SLB(K),K=1,NBR)
8500 FORMAT('0THE GLOBAL SLOPE(RAD) AT EACH BRANCH CONNECTION:',5D15.6)
     WRITE (MWRITE,5250) NBR
5250  FORMAT('0THE ATTACHMENT POINT CODE FOR THE ',I4,' BRANCHES IS AS
    @ FOLLOWS:')
     WRITE(MWRITE,5260) (LATT(L),L=1,NBR)
5260 FORMAT(' ',5I8)
     WRITE(MWRITE,5261)
5261 FORMAT(' WHERE -1= INNER AND 0 = OUTER SURFACES.  1,2,3 INDICATE M
    @IDSURFACE OF CORRESPONDING LAYER.')
     NODP(NBR+1) = NNS
     NELTT= 0
     DO 5316 I= 1,NBR
     NELTT=NELTT+ NELT(I)
```

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```
      NO1 = NODP(I) + 1
      NOD=NODP(I+1)
      DO 5315 J = NO1,NOD
      KN= J+NELTT
      Y(KN) = YK(J)
      Z(KN)= ZK(J)
      DO 5401 L=1,NLAY
 5401 H(KN,L) = HK(J,L)
      ANG(KN) = ANGK(J)
      MK(J) = KN
 5315 CONTINUE
 5316 CONTINUE
      IF(NODP(1).NE.1) GOTO 5320
      KN= 1+NELT(1)
      Y(KN) = YK(1)
      Z(KN) = ZK(1)
      DO 5410 L=1,NLAY
 5410 H(KN,L) = HK(1,L)
      ANG(KN) = ANGK(1)
      MK(1) = KN
       NEL = NELT(1)
      DO 5325 I= 1,NEL
      Y(I)= YB(1,I)
      Z(I) = ZB(1,I)
      ANG(I) = ANB(1,I)
      H(I,1) = HB(1,I)
      IF(NLAY.EQ.1)  GO TO 5325
      DO 6455 MT=2,NLAY
 6455 H( I,MT)  =0.0
 5325 CONTINUE
      GOTO 5322
 5320 NO1= NODP(1)
       DO 5321 J = 1,NO1
 5321 MK(J) = J
 5322 NELTT=0
      DO 5330 I= 1,NBR
```

```
      IF(NODP(I).EQ.1) GOTO 5334                                      BRAN1450
      NEL = NELT(I)                                                   BRAN1460
      DO 5335 J= 1,NEL                                                BRAN1470
      KN= J+ NODP(I) + NELTT                                          BRAN1480
      Y(KN) = YB(I,J)                                                 BRAN1490
      Z(KN) = ZB(I,J)                                                 BRAN1500
      ANG(KN) = ANB(I,J)                                              BRAN1510
      H(KN,1) = HB(I,J)                                               BRAN1520
      IF(NLAY.EQ.1)  GO TO 5335                                       BRAN1530
      DO 6450 MT=2,NLAY                                               BRAN1540
 6450 H(KN,MT)  =0.0                                                  BRAN1550
 5335 CONTINUE                                                        BRAN1560
 5334 NELTT= NELTT + NELT(I)                                          BRAN1570
 5330 CONTINUE                                                        BRAN1580
      NZB = 0                                                         BRAN1590
      NYB = 0                                                         BRAN1600
      LTIME= 0                                                        BRAN1610
      LELT = 1                                                        BRAN1620
      DO 5100 J = 1,NS                                                BRAN1630
      NXB = J + NYB                                                   BRAN1640
      IF( NXB.EQ.MK(J)) GO TO 5100                                    BRAN1650
      MKL = 0                                                         BRAN1660
      LTIME= LTIME+1                                                  BRAN1670
      MXX  = NXB-2                                                    BRAN1680
      NYB= NYB+ NELT(LTIME)                                           BRAN1690
      IF(LHIT(LTIME).NE.0) GO TO 5140                                 BRAN1700
      NZB = NZB+NELT(LTIME)                                           BRAN1710
      IF(J.EQ.1) MXX=0                                                BRAN1720
      MKL=MKL+MXX                                                     BRAN1730
      DO 5130 I= LELT,NZB                                             BRAN1740
      MKL=MKL+1                                                       BRAN1750
 5130 LMT(I) = MKL                                                    BRAN1760
      LELT = NZB+1                                                    BRAN1770
 5140 IF (LTIME.EQ.NBR)  GOTO 5145                                    BRAN1780
 5100 CONTINUE                                                        BRAN1790
 5145 CONTINUE                                                        BRAN1800
```

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```
      LELT=0
      NYB=0
      LTIME = 0
      DO 5275 J= 1,NS
      NXB=J+NYB
      IF(NXB.EQ.MK(J)) GO TO 5275
      LTIME=LTIME+1
      MXX  = NXB-2
      NYB=NYB+NELT(LTIME)
      IF(J.EQ. 1) MXX=0
      LELT=MXX+1
      NZB= MXX+NELT(LTIME)
      DO 5280 I=LELT,NZB
 5280 MKE(I) = LTIME+1
      IF(LTIME.EQ.NBR) GO TO 5285
 5275 CONTINUE
 5285 CONTINUE
      NODP(NBR+1) = IK
      NT= NELT(1) + NODP(2) + NELT(2) -1
      NTT= NELT(1) + NELT(2)
      IF(NBR.EQ.1) NT = IK
      IF (NODP(1).EQ.1) GO TO 5340
      NT= NODP(1)+ NELT(1) - 1
      NTT= NELT(1)
 5340 DO 5345 I= 1,NT
      NVEC(I,1) = I
 5345 NVEC(I,2) = I+1
      NO = 2
      IF(NODP(1) - 1) 5350,5355,5350
 5355 IF(NBR.EQ.1)  GO TO  5350
      NO= 3
 5350 NB1 = NBR+1
      DO 5360 I = NO,NB1
      IF (NT.EQ.IK) GO TO  5400
      NT= NT+1
      NVEC(NT,1) = NT-NELT(I-1)
```

```
      NVEC(NT,2) = NT+1
      NT = NT+1
      NTT= NTT+ NELT(I)
      NOO  = NTT+ NODP(I) -1
      IF(NODP(I).EQ.IK)  NOO=IK
      DO 5365 J=NT,NOO
      NVEC(J,1)  = J
 5365 NVEC(J,2)  = J+1
      NT = NOO
 5360 CONTINUE
 5400 CONTINUE
      IF(EXANG.EQ.360.0) NVEC(IK,2) = 1
      WRITE(MWRITE,110)
  110 FORMAT(//,' PRESENT ELEM. NO.',5X,'NODE1',5X,'NODE2',5X,'SUBSTRUCT
     @URE',5X,'SUBST. ELEM. NO.')
      JEL = 0
      JL=0
      DO 115 IR=1,IK
      IF(MKE(IR).NE.1) GO TO 120
      JL=0
      JEL=JEL+1
      JELE=JEL
      GO TO 125
  120 JL=JL+1
      JELE=JL
  125 WRITE(MWRITE,126) IR,NVEC(IR,1),NVEC(IR,2),MKE(IR),JELE
  126 FORMAT(' ',4X,I5,11X,I5,5X,I5,7X,I5,13X,I5)
  115 CONTINUE
      WRITE(MWRITE,130)
  130 FORMAT('0THE UPDATED NODE NUMBERS FOR THE MAIN STRUCTURE, GIVEN IN
     @ THEIR ORIGINAL NUMBERING ORDER:')
      WRITE (MWRITE,5323) (MK(L),L=1,NNS)
 5323 FORMAT ('0',25I5)
      WRITE(MWRITE,1010)
 1010 FORMAT(//,' NOTE:  THE ELEMENT NUMBERS REFERRED TO BELOW ARE PRESE
     @NT ELEMENT NUMBERS',//)
```


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```
      WRITE (MWRITE,2110)                                                BRAN2530
      WRITE (MWRITE,2100)  (LMT(N),N=1,NS)                               BRAN2540
 2100 FORMAT(' ',10I5)                                                   BRAN2550
 2110 FORMAT('0ELEMENTS THAT CAN NOT BE IMPACTED:')                      BRAN2560
      READ(MREAD,5300) NDISB                                             BRAN2570
      IF(NDISB.EQ.0) GO TO 8100                                          BRAN2580
      DO 8101 I=1,NDISB                                                  BRAN2590
      READ(MREAD,8102) NEDIB,NBDI,ANGDB                                  BRAN2600
 8102 FORMAT(2I5,D15.6)                                                  BRAN2610
      ANGDB= ANGDB*PIE/180.0                                             BRAN2620
      NDIS= NDIS+1                                                       BRAN2630
      ANGDI(NDIS) = ANGDB                                                BRAN2640
      L= NODP(NBDI)                                                      BRAN2650
      K=MK(L)                                                            BRAN2660
      IF(L.EQ.1) K=1                                                     BRAN2670
 8103 NEDI(NDIS)  = NEDIB +K -1                                          BRAN2680
 8101 CONTINUE                                                           BRAN2690
 8100 CONTINUE                                                           BRAN2700
C     ESTABLISH BOUNDARY CONDITIONS                                      BRAN2710
C     VECTOR YK(51) NOW CONTAINS ACTUAL NODE NUMBER OF ORIGINAL DEFLECTOBRAN2720
      READ(MREAD,5300) NBCONB                                            BRAN2730
      IF(NBCONB.EQ.0) GOTO 5376                                          BRAN2740
      READ(MREAD,5300) (NBCB(L),NODBB(L),LBR(L),L=1,NBCONB)              BRAN2750
      DO 5370 L = 1,NBCONB                                               BRAN2760
      NNNN= LBR(L)                                                       BRAN2770
      NO1= NODP(NNNN)                                                    BRAN2780
      NELTT= 0                                                           BRAN2790
      LB= LBR(L)-1                                                       BRAN2800
      DO 5375 J= 1,LB                                                    BRAN2810
 5375 NELTT= NELTT + NELT(J)                                             BRAN2820
      IF (LB.NE.0) GOTO 5371                                             BRAN2830
      NELTT = 0                                                          BRAN2840
      IF(NODP(1).EQ.1) GO TO 5370                                        BRAN2850
 5371 NODBB(L)  = NODBB(L) + NO1 + NELTT                                 BRAN2860
 5370 CONTINUE                                                           BRAN2870
 5376 CONTINUE                                                           BRAN2880
```

```
C          DETERMINE LEADING NON ZERO TERM IN EACH ROW
      DO 15 I= 1,8
   15 ICOL(I) = 1
      IKM1 = IK-1
      NI = NS*4
      IF(EXANG.NE.360.0) GO TO 210
      DO 16 I = 2,IKM1
      J=  (I+1) *4
      ICOL(J)    = NVEC(I,1)  *  4 - 3
      ICOL(J-1)  = NVEC(I,1)  *  4 - 3
      ICOL(J-2)  = NVEC(I,1)  *  4 - 3
      ICOL(J-3)  = NVEC(I,1)  *  4 - 3
   16 CONTINUE
      ICOL(IK*4)      =  1
      ICOL(IK*4-1)    =  1
      ICOL(IK*4-2)    =  1
      ICOL(IK*4-3)    =  1
      GO TO 218
  210 DO 211 I= 2,IK
      J=  (I+1) *4
      ICOL(J)    = NVEC(I,1)  *  4 - 3
      ICOL(J-1)  = NVEC(I,1)  *  4 - 3
      ICOL(J-2)  = NVEC(I,1)  *  4 - 3
      ICOL(J-3)  = NVEC(I,1)  *  4 - 3
  211 CONTINUE
  218 CONTINUE
      DO 5341 M= 1,IK
 5341 YK(M) = 0.0
      DO 5342 M = 1,NBR
      IF (NODP(M).NE.1) GO TO 5343
      NNNN= NELT(M)
      YK(NNNN) = 1.0
      ROT(M,1) = 0.0
       MKS = NELT(M) + 1
      ROT(M,2) = ANB(M,MKS) - ANGK(1)
      GO TO 5342
```

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```
5343 N= NODP(M)                                                  BRAN3250
     NM= MK(N)                                                   BRAN3260
     YK(NM) = 1.0                                                BRAN3270
     ROT(M,1) = 1.0                                              BRAN3280
      MKS = NELT(M) + 1                                          BRAN3290
     ROT(M,2) = ANB(M,MKS) - ANG(NM)                             BRAN3300
5342 CONTINUE                                                    BRAN3310
     RETURN                                                      BRAN3320
     END                                                         BRAN3330
```

```
      SUBROUTINE  ELMPP(AMASS,STIFK,ISIZE,AEP,DEP,NV1,REACK,REACM,ELMPB)
C      TO FIND THE MASS MATRIX STIFFNESS MATRIX AND STRAIN NODAL
C      DISPLACEMENT TRANSFORMATION MATRICES
       IMPLICIT REAL*8(A-H,C-Z)
      DIMENSION REACK(1),REACM(1)
      DIMENSION AEP(NV1,3,8),DEP(NV1,2,3,8)
      DIMENSION AE1(3,8)  , DUMMY(8)  ,BX(2)
      DIMENSION TR(4,4),TRAN(8,8)
       DIMENSION A(8,8),LMI(8),MMI(8),D(8,8),ELM(8,8),
     *ELMAS(8,8),AMASS(1),E(8,8),EK1(8,8),ELK(8,8),STIFK(1),
     *BE1(3,3,8),BNG(51)
     *,D1(3,8),D2(3,3),D3(3,8),D4(8,8),E1(2,8),E2(2,2),E3(2,8),E4(8,8)
      COMMON/MAT/YOUNG(3,6),DS(3,6),SNO(3,5,6),NSFL(3,6),P(3,6),NLAY
      COMMON /FG/ IK,IKK,ICP,LREF,NOGA,NFL,NI,ICOL(205),INUM(205)
     *,NBCOND,NBC(7),NODEB(7),KROW(8),NDEX(8),NIRREG
       COMMON/FC/ Y(51),Z(51),ANG(51),H(51,3)
       COMMON/BA/ BEP(50,3,3,8),AL(50),AXG(3),AWG(3),WET(50,3),
     *CE1(50,3),CE2(50,3),CE3(50,3),CM1(50,3),CM2(50,3),CM3(50,3)
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      COMMON/ADSP/ AZET(50),ASP(50),YSP(50),ZSP(50),LKK(50,11)
      COMMON/BOUN/YK(51),NBCONB,NBCB(7),NODBB(7),MK(51),RCT(5,2)
     *,XDIST(6),DRCT(50),NODP(6)
      COMMON /BR/ NVEC(51,2), LMT(51)
      COMMON /TAM/ MKE(51)
       SIN(Q)=DSIN(Q)
       COS(Q)=DCOS(Q)
       ATAN(Q)=DATAN(Q)
       SQRT(Q)=DSQRT(Q)
       DO 18 L=1,ISIZE
       STIFK(L)=0.0
 18    AMASS(L)=0.0
 50    DO 101 IR=1,IK
      K1 = NVEC(IR,1)
      K2 = NVEC(IR,2)
      L= MKE(IR)  -1
      P5=Z(K2)-Z(K1)
```


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      P6=Y(K2)-Y(K1)                                                    ELMP0370
       P7=ANG(K2   )-ANG(K1)                                            ELMP0380
      IF(YK(IR).EQ.1.0)  P7=ANG(K2)  - ROT(L,2)-ANG(K1)                ELMP0390
      IF(YK(IR).EQ.1.0.AND.ROT(L,1).EQ.0.0)  P7=ROT(L,2)+ANG(K2)-ANG(K1) ELMP0400
      IF(YK(IR).EQ.2.0)   P7= ANG(K2)- DROT(IR)  - ANG(K1)             ELMP0410
      IF(YK(IR).EQ.3.0)  P7= ROT(L,2)+ANG(K2)-DROT(IR)-ANG(K1)         ELMP0420
      PIE= 3.141592653589793D+00                                        ELMP0430
      PIE2= 2.0*PIE                                                     ELMP0440
      PIE32= 1.5 *PIE                                                   ELMP0450
      ANG2=ANG(K2)                                                      ELMP0460
      ANG1=ANG(K1)                                                      ELMP0470
      IF(YK(IR).EQ.1.0.AND.ROT(L,1).EQ.0.0) ANG(K2)=ROT(L,2)+ANG(K2)    ELMP0480
      IF(YK(IR).EQ.1.0.AND.ROT(L   ,1).EQ.1.0)ANG(K1)=ROT(L   ,2)+ANG(K1) ELMP0490
      IF(YK(IR).EQ.2.0)  ANG(K1)= DROT(IR)  + ANG(K1)                   ELMP0500
      IF(YK(IR).EQ.3.0)  ANG(K1)= DROT(IR)+  ANG(K1)                    ELMP0510
      IF(YK(IR).EQ.3.0)  ANG(K2)= ROT(L,2)+ANG(K2)                      ELMP0520
      APHA = PIE / 2.0                                                  ELMP0530
      IF(P5.LT.0.0)  APHA= -APHA                                        ELMP0540
      IF(P6.NE.0.0)  APHA= ATAN(P5/P6)                                  ELMP0550
      IF(P6.LT.0.0.AND.P5.LT.0.0)APHA=APHA-PIE                          ELMP0560
       IF(P6.LT.0.0 .AND.  P5.GE.0.0)  APHA=APHA+PIE                    ELMP0570
       IF(P7 .EQ.  0.0)  GO TO 60                                       ELMP0580
       AL(IR)=P7*SQRT(P5**2+P6**2)/SIN(P7/2.)/2.                        ELMP0590
      IF(P7.GT.PIE32) AL(IR)=(P7-PIE2)*SQRT(P5**2+P6**2)/SIN(P7/2.-PIE) ELMP0600
     */2.0                                                              ELMP0610
      IF(P7.LT.(-PIE32      ))AL(IR)=(P7+PIE2      )*SQRT(P5**2+P6**2)  ELMP0620
     */SIN(P7/2.+PIE        )/2.                                        ELMP0630
       GO TO 61                                                         ELMP0640
60     AL(IR)=SQRT(P5**2+P6**2)                                         ELMP0650
61     BNG(IR+1)=ANG(K2   )                                             ELMP0660
       BNG(IR)=ANG(K1)                                                  ELMP0670
      IF(P7.GT.(PIE32 ).AND.APHA.LT.0.0)  BNG(IR+1)=ANG(K2)   -PIE2     ELMP0680
      IF(P7.GT.(PIE32 ).AND.APHA.GT.0.0)  BNG(IR)=ANG(K1)+PIE2          ELMP0690
      IF(P7.LT.(-PIE32 ).AND.APHA.GT.0.0)  BNG(IR+1)=ANG(K2)   +PIE2    ELMP0700
      IF(P7.LT.(-PIE32 ).AND.APHA.LT.0.0)  BNG(IR)=ANG(K1)-PIE2         ELMP0710
       BZER=BNG(IR)-APHA                                                ELMP0720
```

```
      B1=(-2.*BNG(IR+1)-4.*BNG(IR)+6.*APHA)/AL(IR)
      B2=(3.*BNG(IR+1)+3.*BNG(IR)-6.*APHA)/AL(IR)**2
     ANG(K2)= ANG2
     ANG(K1)= ANG1
      DO 102 I=1,8
      DO 102 J=1,8
      A(I,J)=0.0
      E(I,J)=0.0
  102 D(I,J)=0.0
      A(1,1)= COS(BNG(IR)-APHA)
      A(1,2)= SIN(BNG(IR)-APHA)
      A(2,1)=-SIN(BNG(IR)-APHA)
      A(2,2)= COS(BNG(IR)-APHA)
      A(3,3)=1.
      A(5,1)=COS(BNG(IR+1)-APHA)
      A(5,2)=SIN(BNG(IR+1)-APHA)
      A(5,3)=P6*SIN(BNG(IR+1))-P5*COS(BNG(IR+1))
      A(6,1)=-SIN(BNG(IR+1)-APHA)
      A(6,2)=COS(BNG(IR+1)-APHA)
      A(6,3)=P6*COS(BNG(IR+1))+P5*SIN(BNG(IR+1))
      A(7,3)=1.
      A(4,4)=1.
      A(5,4)=AL(IR)
      A(5,7)=AL(IR)**2
      A(5,8)=AL(IR)**3
      A(6,5)=AL(IR)**2
      A(6,6)=AL(IR)**3
      P8=B1+2.*B2*AL(IR)
      A(7,4)=AL(IR)*P8
      A(7,5)=2.*AL(IR)
      A(7,6)=3.*AL(IR)**2
      A(7,7)=AL(IR)**2*P8
      A(7,8)=AL(IR)**3*P8
      A(8,4)=1.
      A(8,5)=-AL(IR)**2*P8
      A(8,6)=-AL(IR)**3*P8
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```
      A(8,7)=2.*AL(IR)
      A(8,8)=3.*AL(IR)**2
      CALL MINV(A,8,DET,LMI,MMI)
      DO 103 J=1,NOGA
      WET(IR,J)=AL(IR)*AWG(J)
      ZET=AL(IR)*AXG(J)
      PHIP=B1+2.*B2*ZET
      PHI=BZER+B1*ZET+B2*ZET**2
     YZET= 0.0
      ZZET=0.0
      DO 104 JJ=1,NOGA
      P2=BZER+B1*ZET*AXG(JJ)+B2*(ZET*AXG(JJ))**2+APHA
      YZET=YZET+COS(P2)*ZET*AWG(JJ)
  104 ZZET=ZZET+SIN(P2)*ZET*AWG(JJ)
      P3=YZET*SIN(PHI+APHA)-ZZET*COS(PHI+APHA)
      P4=YZET*COS(PHI+APHA)+ZZET*SIN(PHI+APHA)
      DO 201 M=1,3
      DO 201 N=1,8
  201 BE1(J,M,N)=0.0
      BE1(J,1,4)=1.
      BE1(J,1,5)=-ZET**2*PHIP
      BE1(J,1,6)=-ZET**3*PHIP
      BE1(J,1,7)=2.*ZET
      BE1(J,1,8)=3.*ZET**2
      BE1(J,2,3)=1.
      BE1(J,2,4)=ZET*PHIP
      BE1(J,2,5)=2.*ZET
      BE1(J,2,6)=3.*ZET**2
      BE1(J,2,7)=ZET**2*PHIP
      BE1(J,2,8)=ZET**3*PHIP
      BE1(J,3,4)=-PHIP-ZET*2.*B2
      BE1(J,3,5)=-2.
      BE1(J,3,6)=-6.*ZET
      BE1(J,3,7)=-2.*ZET*PHIP-ZET**2*2.*B2
      BE1(J,3,8)=-3.*ZET**2*PHIP-ZET**3*2.*B2
      DO 202 M=1,3
```

```
      DO 202 N=1,8
      BEP(IR,J,M,N)=0.0
      DO 202 K=1,8
202   BEP(IR,J,M,N)=BEP(IR,J,M,N)+BE1(J,M,K)*A(K,N)
      DO 115 K=1,3
      DO 115 L=1,8
115   D1(K,L)=0.0
      DO 116 K=1,2
      DO 116 L=1,8
116   E1(K,L)=0.0
      D1(1,1)= COS(PHI)
      D1(1,2)= SIN(PHI)
      D1(1,3)=P3
      D1(1,4)=ZET
      D1(1,7)=ZET**2
      D1(1,8)=ZET**3
      D1(2,1)=- SIN(PHI)
      D1(2,2)= COS(PHI)
      D1(2,3)=P4
      D1(2,5)=ZET**2
      D1(2,6)=ZET**3
      D1(3,3)=1.
      D1(3,4)=ZET*PHIP
      D1(3,5)=2.*ZET
      D1(3,6)=3.*ZET**2
      D1(3,7)=ZET**2*PHIP
      D1(3,8)=ZET**3*PHIP
      D2(1,1)=CM1(IR,J)
      D2(1,2)=0.0
      D2(1,3)=CM2(IR,J)
      D2(2,1)=0.0
      D2(2,2)=CM1(IR,J)
      D2(2,3)=0.0
      D2(3,1)=CM2(IR,J)
      D2(3,2)=0.0
      D2(3,3)=CM3(IR,J)
```

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      E1(1,4)=1.                                                        ELMP1810
      E1(1,5)=-ZET**2*PHIP                                              ELMP1820
      E1(1,6)=-ZET**3*PHIP                                              ELMP1830
      E1(1,7)=2.*ZET                                                    ELMP1840
      E1(1,8)=3.*ZET**2                                                 ELMP1850
      E1(2,4)=-PHIP-ZET*2.*B2                                           ELMP1860
      E1(2,5)=-2.                                                       ELMP1870
      E1(2,6)=-6.*ZET                                                   ELMP1880
      E1(2,7)=-2.*ZET*PHIP-ZET**2*2.*B2                                 ELMP1890
      E1(2,8)=-3.*ZET**2*PHIP-ZET**3*2.*B2                              ELMP1900
      E2(1,1)=CE1(IR,J)                                                 ELMP1910
      E2(1,2)=CE2(IR,J)                                                 ELMP1920
      E2(2,1)=CE2(IR,J)                                                 ELMP1930
      E2(2,2)=CE3(IR,J)                                                 ELMP1940
      DO 110 K=1,3                                                      ELMP1950
      DO 110 L=1,8                                                      ELMP1960
      D3(K,L)=0.0                                                       ELMP1970
      DO 110 M=1,3                                                      ELMP1980
  110 D3(K,L)=D3(K,L)+D2(K,M)*D1(M,L)                                   ELMP1990
      DO 111 K=1,8                                                      ELMP2000
      DO 111 L=1,8                                                      ELMP2010
      D4(K,L)=0.0                                                       ELMP2020
      DO 111 M=1,3                                                      ELMP2030
  111 D4(K,L)=D4(K,L)+D1(M,K)*D3(M,L)                                   ELMP2040
      DO 113 K=1,2                                                      ELMP2050
      DO 113 L=1,8                                                      ELMP2060
      E3(K,L)=0.0                                                       ELMP2070
      DO 113 M=1,2                                                      ELMP2080
  113 E3(K,L)=E3(K,L)+E2(K,M)*E1(M,L)                                   ELMP2090
      DO 114 K=1,8                                                      ELMP2100
      DO 114 L=1,8                                                      ELMP2110
      E4(K,L)=0.0                                                       ELMP2120
      DO 114 M=1,2                                                      ELMP2130
  114 E4(K,L)=E4(K,L)+E1(M,K)*E3(M,L)                                   ELMP2140
      DO 112 K=1,8                                                      ELMP2150
      DO 112 L=1,K                                                      ELMP2160
```

```
      F(K,L)=F(K,L)+F4(K,L)*WET(IR,J)
  112 D(K,L)=D(K,L)+D4(K,L)*WET(IR,J)
  103 CONTINUE
      DO 105 I=1,7
      IP1=I+1
      DO 105 J=IP1,8
      E(I,J)=E(J,I)
  105 D(I,J)=D(J,I)
      DO 106 I=1,8
      DO 106 J=1,8
     EK1(I,J)=0.0
      ELM(I,J)=0.0
      DO 106 K=1,8
      EK1(I,J)=EK1(I,J)+A(K,I)*E(K,J)
  106 ELM(I,J)=ELM(I,J)+A(K,I)*D(K,J)
      DO 107 I=1,8
      DO 107 J=1,8
      ELK(I,J)=0.0
      ELMAS(I,J)=0.0
      DO 107 K=1,8
      ELK(I,J)=ELK(I,J)+EK1(I,K)*A(K,J)
  107 ELMAS(I,J)=ELMAS(I,J)+ELM(I,K)*A(K,J)
     IF(YK(IR).EQ.0.0) GOTO 504
     CALL ROTAT(3,ELK,DUMMY,IR)
     CALL ROTAT(3,ELMAS,DUMMY,IR)
  504 CONTINUE
     IF(ELMFB.EQ.0.0) GOTO  8320
     DO 1000 I=1,4
     IF(I.EQ.3.OR.I.EQ.4) GOTO 1000
     ELMAS(I,I)= ELMAS(I,I)+ ELMAS(I,I+4)
 1000 CONTINUE
     DO 1030  I=5,6
     ELMAS(I,I)= ELMAS(I,I)  + ELMAS(I,I-4)
 1030 CONTINUE
     DO 1010 I=1,8
     DO 1010 J=1,8
```


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```
      IF(I.EQ.J) GOTO 1010
      ELMAS(I,J) = 0.0
 1010 CONTINUE
      WRITE(MWRITE,1020) ((ELMAS(I,J),J=1,8),I=1,8)
 1020 FORMAT(' ', 8D15.6)
 8320 CONTINUE
  502  CALL ASSEM(IR,IK,ELK,STIFK,ICP,INUM)
       CALL ASSEM(IR,IK,ELMAS,AMASS,ICP,INUM)
      IF(IKK(IR,1) .EQ.0)  GOTO 8200
      NPE= IKK(IR,1)
      DO 8210 NO=1,NPE
      MO = NO+1
      M= IKK(IR,MO)
      ZET= AZET(M) * AL(IR)
      PHIP= B1+2.0*B2*ZET
      DO8240 I=1,3
      DO 8240 N=1,8
 8240 AE1(I,N) = 0.0
      AE1(1,4) =1.0
      AE1(1,5) = -ZET**2*PHIP
      AE1(1,6) = -ZET**3*PHIP
      AE1(1,7)= 2.*ZET
      AE1(1,8) = 3.*ZET**2
      AE1(2,3) = 1.0
      AE1(2,4) = ZET*PHIP
      AE1(2,5) = AE1 (1,7)
      AE1(2,6) = AE1(1,8)
      AE1(2,7) =-AE1(1,5)
      AE1(2,8) =-AE1(1,6)
      AE1(3,4) = -PHIP-ZET*2.*B2
      AE1(3,5) = -2.0
      AE1(3,6)= -6.*ZET
      AE1(3,7)=-2.0*ZET*PHIP-ZET**2*2.0*B2
      AE1(3,8)=-3.*ZET**2*PHIP-ZET**3*2.0*B2
      DO 8245 I=1,3
      DO 8245 N= 1,8
```

```
      AEP(M,I,N) = 0.0
      DO 8245 K= 1,8
 8245 AEP(M,I,N) = AEP(M,I,N)  +AE1(I,K)*A(K,N)
 8210 CONTINUE
 8200 CONTINUE
      BX(1) =0.0
      BX(2) = 1.0
      DO 303 J=1,2
      ZET= AL(IR)* BX(J)
      PHIP= B1+2.0*B2*ZET
      DO 301 M=1,3
      DO 301 N= 1,8
  301 BE1(J,M,N) = 0.0
       BE1(J,1,4)=1.
       BE1(J,1,5)=-ZET**2*PHIP
       BE1(J,1,6)=-ZET**3*PHIP
       BE1(J,1,7)=2.*ZET
       BE1(J,1,8)=3.*ZET**2
       BE1(J,2,3)=1.
       BE1(J,2,4)=ZET*PHIP
       BE1(J,2,5)=2.*ZET
       BE1(J,2,6)=3.*ZET**2
       BE1(J,2,7)=ZET**2*PHIP
       BE1(J,2,8)=ZET**3*PHIP
       BE1(J,3,4)=-PHIP-ZET*2.*B2
       BE1(J,3,5)=-2.
       BE1(J,3,6)=-6.*ZET
       BE1(J,3,7)=-2.*ZET*PHIP-ZET**2*2.*B2
       BE1(J,3,8)=-3.*ZET**2*PHIP-ZET**3*2.*B2
      DO 302 M=1,3
      DO 302 N=1,8
      DEP(IR,J,M,N) =0.0
      DO 302 K=1,8
  302 DEP(IR,J,M,N) = DEP(IR,J,M,N)+BE1(J,M,K)*A(K,N)
  303 CONTINUE
 101   CONTINUE
```


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```
      DO 8300 I=1,ISIZE                                                 ELMP3250
      REACK(I) = STIFK(I)                                               ELMP3260
 8300 REACM(I)= AMASS(I)                                                ELMP3270
       IF(NBCOND .EQ.0) RETURN                                          ELMP3280
       DO 91 I=1,NBCOND                                                 ELMP3290
       JT4=NODEB(I)*4                                                   ELMP3300
       JT4M3=JT4-3                                                      ELMP3310
       JT4M2=JT4-2                                                      ELMP3320
       JT4M1=JT4-1                                                      ELMP3330
      IF(ELMPB.NE.0.0) GOTO 8310                                        ELMP3340
       CALL ERC(JT4M3,AMASS,NI,ICOL,INUM)                               ELMP3350
      IF(NBC(I).EQ.1.OR.NBC(I).EQ.2)CALL ERC(JT4M1,AMASS,NI,ICOL,INUM)  ELMP3360
      IF(NBC(I).EQ.2.OR.NBC(I).EQ.3)CALL ERC(JT4M2,AMASS,NI,ICOL,INUM)  ELMP3370
 8310 CONTINUE                                                          ELMP3380
       CALL ERC(JT4M3,STIFK,NI,ICOL,INUM)                               ELMP3390
      IF(NBC(I).EQ.1.OR.NBC(I).EQ.2)CALL ERC(JT4M1,STIFK,NI,ICOL,INUM)  ELMP3400
      IF(NBC(I).EQ.2.OR.NBC(I).EQ.3)CALL ERC(JT4M2,STIFK,NI,ICOL,INUM)  ELMP3410
 91    CONTINUE                                                         ELMP3420
       RETURN                                                           ELMP3430
      END                                                               ELMP3440
```

```
      SUBROUTINE ERC(II,STIFM,NI,ICOL,INUM)                             ERC 0010
C     FOR ELIMINATING ROWS AND COLUMNS IN STIFM                         ERC 0020
      IMPLICIT REAL*8 (A-H,O-Z)                                         ERC 0030
      DIMENSION STIFM(1),ICOL(1),INUM(1)                                ERC 0040
     IC=ICOL(II)                                                        ERC 0050
     DO 101 J=IC,II                                                     ERC 0060
      L=J+INUM(II)                                                      ERC 0070
101  STIFM(L)=0.                                                        ERC 0080
     DO 102 I=II,NI                                                     ERC 0090
     IC1=ICOL(I)                                                        ERC 0100
     IF(II-IC1) 102,103,103                                             ERC 0110
 103  L=II+INUM(I)                                                      ERC 0120
     STIFM(L)=0.                                                        ERC 0130
102  CONTINUE                                                           ERC 0140
      L=II+INUM(II)                                                     ERC 0150
     STIFM(L)=1.                                                        ERC 0160
     RETURN                                                             ERC 0170
     END                                                                ERC 0180
```


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```
      SUBROUTINE FAC   (STIFM,NCOL,KROW,NDEX,IDET,NTAPE6,NROWS,NIRREG,IC)FACT0010
C      LOWER TRIANGULAR FACTOR OF STIFM MATRIX IS COMPUTED AND STORED   FACT0020
       IMPLICIT REAL*8(A-H,O-Z)                                         FACT0030
      DIMENSION STIFM(1),NCOL(1),KROW(1),NDEX(1),IC(1)                  FACT0040
       ABS(Q)=DABS(Q)                                                   FACT0050
C     STIFM                                                             FACT0060
C     PROCESS COLUMN 1                                                  FACT0070
      I=1                                                               FACT0080
      IDET=0                                                            FACT0090
      IF (STIFM(1)) 152,122,101                                         FACT0100
152   IDET=IDET+1                                                       FACT0110
 101  INDEX=0                                                           FACT0120
      IROW=1                                                            FACT0130
      TEST=1.0                                                          FACT0140
      KN=1                                                              FACT0150
      DO 103 I=2,NROWS                                                  FACT0160
      KN=KN+I-NCOL(I)                                                   FACT0170
      IF (NCOL(I)-1) 103,102,103                                        FACT0180
  102 STIFM(KN)=STIFM(KN)/STIFM(1)                                      FACT0190
  103 CONTINUE                                                          FACT0200
      DO 121 I=2,NROWS                                                  FACT0210
      IP1=I+1                                                           FACT0220
      IM1=I-1                                                           FACT0230
      SUM=0.0                                                           FACT0240
      NCK=0                                                             FACT0250
      III=NCOL(I)                                                       FACT0260
      INDEX=INDEX+I-III                                                 FACT0270
      IF (IM1-III) 150,140,140                                          FACT0280
C     DIAGONAL TERMS                                                    FACT0290
  140 DO 104 J=III,IM1                                                  FACT0300
      IJ=INDEX+J                                                        FACT0310
  104 SUM=SUM+STIFM(IJ)*STIFM(IJ)*STIFM(IC(J)+J)                        FACT0320
  150 II=INDEX+I                                                        FACT0330
      SUM=STIFM(II)-SUM                                                 FACT0340
      IF (SUM) 151,122,105                                              FACT0350
 151  IDET= IDET +1                                                     FACT0360
```

```
105   TES= ABS(SUM/STIFM(II))                                        FACT0370
      IF (TES-TEST) 106,107,107                                      FACT0380
  106 TEST=TES                                                       FACT0390
      IROW=I                                                         FACT0400
  107 STIFM(II)= SUM                                                 FACT0410
C     OFF DIAGONAL TERMS                                             FACT0420
      IF (I-NROWS) 108,121,121                                       FACT0430
  108 KNDEX=INDEX                                                    FACT0440
  109 DO 116 K=IP1,NROWS                                             FACT0450
      KK=NCOL(K)                                                     FACT0460
      KNDEX=KNDEX+K-KK                                               FACT0470
      SUM=0.0                                                        FACT0480
      IF (KK-III) 110,130,130                                        FACT0490
  110 KK=III                                                         FACT0500
  130 IF (IM1-KK) 112,131,131                                        FACT0510
  131 DO 111 J=KK,IM1                                                FACT0520
      IJ=INDEX+J                                                     FACT0530
      KJ=KNDEX+J                                                     FACT0540
  111 SUM=SUM+STIFM(IJ)*STIFM(KJ)*STIFM(IC(J)+J)                     FACT0550
  112 IF (I-KK) 114,115,115                                          FACT0560
  114 IF (NIRREG .LE. 0) GO TO 121                                   FACT0570
      IF (NIRREG .GT. NROWS /2) GO TO 116                            FACT0580
      GO TO 190                                                      FACT0590
  115 KI=KNDEX+I                                                     FACT0600
      STIFM(KI)=(STIFM(KI)-SUM)/STIFM(II)                            FACT0610
  116 CONTINUE                                                       FACT0620
      GO TO 121                                                      FACT0630
  190 NCK=NCK+1                                                      FACT0640
      IF (NIRREG .LT. NCK) GO TO 121                                 FACT0650
      IP1=KROW(NCK)                                                  FACT0660
      IF (I .LT. NCOL(IP1)) GO TO 190                                FACT0670
      IF (IP1 .LT. K) GO TO 190                                      FACT0680
      KNDEX=NDEX(NCK)                                                FACT0690
      GO TO 109                                                      FACT0700
  121 CONTINUE                                                       FACT0710
      RETURN                                                         FACT0720
```


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```
  122 WRITE (NTAPE6,1001) I                                                     FACT0730
      IDET=-I                                                                   FACT0740
 1001 FORMAT (37H1 MATRIX NOT POSITIVE DEFINITE IN ROW,I4)                      FACT0750
      WRITE (NTAPE6,1002) SUM                                                   FACT0760
 1002 FORMAT (27H0SQUARE OF DIAGONAL TERM = ,E15.8,/28H0PARTIALLY FACTORFACT0770
     1ED K MATRIX,//)                                                           FACT0780
      RETURN                                                                    FACT0790
      END                                                                       FACT0800
```

```
      SUBROUTINE IDENT(NQR,B,DENS,EPS,SIG,NBR)
       IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION DENS(3,6),EPS(3,5,6),SIG(3,5,6),B(6)
      COMMON/MAT/YOUNG(3,6),DS(3,6),SNO(3,5,6),NSFL(3,6),P(3,6),NLAY
      COMMON /FG/ IK,IKK,ICP,LREF,NOGA,NFL,NI,ICOL(205),INUM(205)
     *,NBCOND,NBC(7),NODEB(7),KROW(8),NDEX(8),NIRREG
      COMMON /ML/ MNEL(6)
       COMMON/FC/ Y(51),Z(51),ANG(51),H(51,3)
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      COMMON /TAM/ MKE(51)
       IF(ICP.GT.0) GO TO 31
       WRITE(MWRITE,2)
2      FORMAT('-*********** A SPATIAL FINITE ELEMENT AND HOUBOLT TEMPORA
     *L OPERATOR PROGRAM',/,'     USED TO CALCULATE THE NONLINEAR RESPONS
     *ES OF A VARIABLE THICKNESS MULTILAYER ',/,'     ARBITRARILY CURVED
     * PARTIAL  RING WITH THE FOLLOWING PARAMETERS ',//)
       GO TO 30
31     WRITE(MWRITE,1)
1      FORMAT('-*********** A SPATIAL FINITE ELEMENT AND HOUBOLT TEMPORA
     *L OPERATOR PROGRAM',/,'     USED TO CALCULATE THE NONLINEAR RESPONS
     *ES OF A VARIABLE THICKNESS MULTILAYER ',/,'     ARBITRARILY CURVED
     * COMPLETE RING WITH THE FOLLOWING PARAMETERS ',//)
   30 CONTINUE
      NBR1 = NBR+1
      DO 600 LSUB=1,NBR1
      IF(LSUB.EQ.1) GOTO 100
      LSUB1 = LSUB-1
      WRITE(MWRITE,115) LSUB1
  115 FORMAT('-PROPERTIES OF BRANCH NUMBER',I4,'  :')
      GOTO 110
  100 WRITE(MWRITE,105)
  105 FORMAT('-PROPERTIES OF THE MAIN STRUCTURE:')
  110 CONTINUE
      NLAP=NLAY
      IF(LSUB.GT.1)  NLAP = 1
      WRITE(MWRITE,3) B(LSUB),MNEL(LSUB),NOGA,NFL,NLAP,LREF
```


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```
3       FORMAT('    WIDTH OF RING (IN)                              =',E15.6,/,  IDNT0370
     *'    NUMBER OF ELEMENTS                                   =',I5,/,     IDNT0380
     *'    NUMBER OF SPANWISE GAUSSIAN POINTS                   =',I5,/,     IDNT0390
     *'    NUMBER OF DEPTHWISE GAUSSIAN POINTS                  =',I5,/,     IDNT0400
     *'    NUMBER OF LAYERS                                     =',I5,/,     IDNT0410
     *'    REFERENCE SURFACE IS THE MIDDLE SURFACE OF LAYER=',I5,/)          IDNT0420
      DO 32 M=1,NLAP                                                         IDNT0430
      WRITE (MWRITE,33) M,DENS(M,LSUB),NSFL(M,LSUB)                          IDNT0440
33      FORMAT('    MATERIAL PROPERTIES OF LAYER                    =',I5,/, IDNT0450
     *'            DENSITY(LB-SEC**2/IN**4)                     =',E15.6,/,  IDNT0460
     *'            NUMBER OF MECHANICAL SUBLAYERS               =',I5,/)     IDNT0470
        NSFLM= NSFL(M,LSUB)                                                  IDNT0480
        WRITE(MWRITE,40)                                                     IDNT0490
40      FORMAT(19X,'    STRAIN          STRESS ')                            IDNT0500
      WRITE(MWRITE,41) (L,EPS(M,L,LSUB),SIG(M,L,LSUB),L=1,NSFLM)            IDNT0510
41      FORMAT(14X,I5,2E15.6)                                                IDNT0520
      IF(DS(M,LSUB).LE.0.0) GO TO 34                                         IDNT0530
      WRITE(MWRITE,35) DS(M,LSUB),P(M,LSUB)                                  IDNT0540
35      FORMAT(9X,' MATERIAL IS STRAIN RATE SENSITIVE WITH ',/,              IDNT0550
     *19X,' D =',E15.6,' P = ',E15.6,/)                                      IDNT0560
        GO TO 32                                                             IDNT0570
34      WRITE(MWRITE,36)                                                     IDNT0580
36      FORMAT(9X,' MATERIAL IS STRAIN RATE INSENSITIVE ',/)                 IDNT0590
32      CONTINUE                                                             IDNT0600
 600  CONTINUE                                                               IDNT0610
        IF(NBCOND .EQ. 0) GO TO 5                                            IDNT0620
        DO 14 I=1,NBCOND                                                     IDNT0630
        IF(NBC(I) .EQ. 1) WRITE(MWRITE,15) NODEB(I)                          IDNT0640
        IF(NBC(I) .EQ. 2) WRITE(MWRITE,16) NODEB(I)                          IDNT0650
        IF(NBC(I) .EQ. 3) WRITE(MWRITE,17) NODEB(I)                          IDNT0660
14      CONTINUE                                                             IDNT0670
15      FORMAT('   SYMMETRY DISPLACEMENT CONDITION AT NODE =',I5)            IDNT0680
16      FORMAT('    CLAMPED DISPLACEMENT CONDITION AT NODE =',I5)            IDNT0690
17      FORMAT('    HINGED  DISPLACEMENT CONDITION AT NODE =',I5)            IDNT0700
        GO TO 18                                                             IDNT0710
5       WRITE(MWRITE,13)                                                     IDNT0720
```

```
13    FORMAT(/,'    THERE IS NO PRESCRIBED DISPLACEMENT CONDITION')       IDNT0730
18     IF(NQR .EQ. 0) GO TO 19                                            IDNT0740
       WRITE(MWRITE,20)                                                   IDNT0750
20     FORMAT(/,'    CONSTRAINTS (ELASTIC FOUNDATION/SPRING) AS DESCRIBEDIDNT0760
     * BY INPUT ',//)                                                     IDNT0770
       GO TO 23                                                           IDNT0780
19     WRITE(MWRITE,21)                                                   IDNT0790
21     FORMAT(/,'    THERE ARE NO ELASTIC SPRING CONSTRAINTS',//)         IDNT0800
23     CONTINUE                                                           IDNT0810
       WRITE(MWRITE,47)                                                   IDNT0820
47     FORMAT(10X,' NODE NO     Y COORD(IN)      Z COORD(IN)      SLOPE ( IDNT0830
     *RAD)       RING THICKNESS(IN) ',/,70X,'      LAYER 1           LAYER IDNT0840
     * 2           LAYER 3 ',/)                                           IDNT0850
       DO 45 I=1,IKK                                                      IDNT0860
45     WRITE(MWRITE,46)I,Y(I),Z(I),ANG(I),(H(I,M),M=1,NLAY)               IDNT0870
46     FORMAT(10X,I5,4X,6E17.6)                                           IDNT0880
       RETURN                                                             IDNT0890
      END                                                                 IDNT0900
```


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```
      SUBROUTINE MINV(A,N,DET,L,M)
C      INVERT MATRIX A
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION A(1),L(1),M(1)
      ABS(Q)=DABS(Q)
C
C        SEARCH FOR LARGEST ELEMENT
C
      DET=1.0
     NK=-N
     DO 80 K=1,N
     NK=NK+N
     L(K)=K
     M(K)=K
     KK=NK+K
     BIGA=A(KK)
     DO 20 J=K,N
     IZ=N*(J-1)
     DO 20 I=K,N
     IJ=IZ+I
 10   IF( ABS(BIGA)- ABS(A(IJ)))15,20,20
   15 BIGA=A(IJ)
     L(K)=I
     M(K)=J
   20 CONTINUE
C
C        INTERCHANGE ROWS
C
     J=L(K)
     IF(J-K) 35,35,25
   25 KI=K-N
     DO 30 I=1,N
     KI=KI+N
     HOLD=-A(KI)
     JI=KI-K+J
     A(KI)=A(JI)
```

```
   30 A(JI) =HOLD
C
C        INTERCHANGE COLUMNS
C
   35 I=M(K)
      IF(I-K) 45,45,38
   38 JP=N*(I-1)
      DO 40 J=1,N
      JK=NK+J
      JI=JP+J
      HOLD=-A(JK)
      A(JK)=A(JI)
   40 A(JI) =HOLD
C
C        DIVIDE COLUMN BY MINUS PIVOT (VALUE OF PIVOT ELEMENT IS
C        CONTAINED IN BIGA)
C
   45 IF(BIGA) 48,46,48
   46 DET=0.0
      RETURN
   48 DO 55 I=1,N
      IF(I-K) 50,55,50
   50 IK=NK+I
      A(IK)=A(IK)/(-BIGA)
   55 CONTINUE
C
C        REDUCE MATRIX
C
      DO 65 I=1,N
      IK=NK+I
      HOLD=A(IK)
      IJ=I-N
      DO 65 J=1,N
      IJ=IJ+N
      IF(I-K) 60,65,60
   60 IF(J-K) 62,65,62
```


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```
   62 KJ=IJ-I+K                                                         MINV0700
      A(IJ)=HOLD*A(KJ)+A(IJ)                                            MINV0710
   65 CONTINUE                                                          MINV0720
C                                                                       MINV0730
C        DIVIDE ROW BY PIVOT                                            MINV0740
C                                                                       MINV0750
      KJ=K-N                                                            MINV0760
      DO 75 J=1,N                                                       MINV0770
      KJ=KJ+N                                                           MINV0780
      IF(J-K) 70,75,70                                                  MINV0790
   70 A(KJ)=A(KJ)/BIGA                                                  MINV0800
   75 CONTINUE                                                          MINV0810
C                                                                       MINV0820
C        PRODUCT OF PIVOTS                                              MINV0830
C                                                                       MINV0840
      DET=DET*BIGA                                                      MINV0850
C                                                                       MINV0860
C        REPLACE PIVOT BY RECIPROCAL                                    MINV0870
C                                                                       MINV0880
      A(KK)=1.0/BIGA                                                    MINV0890
   80 CONTINUE                                                          MINV0900
C                                                                       MINV0910
C        FINAL ROW AND COLUMN INTERCHANGE                               MINV0920
C                                                                       MINV0930
      K=N                                                               MINV0940
  100 K=(K-1)                                                           MINV0950
      IF(K) 150,150,105                                                 MINV0960
  105 I=L(K)                                                            MINV0970
      IF(I-K) 120,120,108                                               MINV0980
  108 JQ=N*(K-1)                                                        MINV0990
      JR=N*(I-1)                                                        MINV1000
      DO 110 J=1,N                                                      MINV1010
      JK=JQ+J                                                           MINV1020
      HOLD=A(JK)                                                        MINV1030
      JI=JR+J                                                           MINV1040
      A(JK)=-A(JI)                                                      MINV1050
```

```
  110 A(JI) =HOLD                                    MINV1060
  120 J=M(K)                                         MINV1070
      IF(J-K) 100,100,125                            MINV1080
  125 KI=K-N                                         MINV1090
      DO 130 I=1,N                                   MINV1100
      KI=KI+N                                        MINV1110
      HOLD=A(KI)                                     MINV1120
      JI=KI-K+J                                      MINV1130
      A(KI)=-A(JI)                                   MINV1140
  130 A(JI) =HOLD                                    MINV1150
      GO TO 100                                      MINV1160
  150 RETURN                                         MINV1170
       END                                           MINV1180
```


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```
      SUBROUTINE OMULT(SQVCT,RWVCT,NCOL,NROWS,ACC,KROW,NDEX,NIRREG)
C     TO FIND ACC OF (SQVCT)*(RWVCT)=(ACC)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION SQVCT(1),RWVCT(1),NCOL(1),ACC(1),KROW(1),NDEX(1)
      INDEX=0
      NROWM=NROWS-1
      IF (NIRREG .GT. 0) GO TO 200
C     HIGH SPEED PRODUCT FOR REGULAR MATRICES
      DO 100 NN=1,NROWM
      SUM=0.0
      IP1=NN+1
      KST=NCOL(NN)
      INDEX=INDEX+NN-KST
      DO 101 KPL=KST,NN
      IJ=INDEX+KPL
  101 SUM=SUM+SQVCT(IJ)*RWVCT(KPL)
C     NOW FOR THE COLUMN ELEMENTS
      JNDEX=IJ
      DO 102 KPL=IP1,NROWS
      IF(NN.LT.NCOL(KPL))GO TO 100
      JNDEX=JNDEX+KPL-NCOL(KPL)
  102 SUM=SUM+SQVCT(JNDEX)*RWVCT(KPL)
  100 ACC(NN)=ACC(NN)+SUM
C     NOW FOR THE LAST ROW
  104 KADD=NCOL(NROWS)
      SUM=0.0
      INDEX=INDEX+NROWS-KADD
      DO 103 KPL=KADD,NROWS
      IJ=INDEX+KPL
  103 SUM=SUM+SQVCT(IJ)*RWVCT(KPL)
      ACC(NROWS)=ACC(NROWS)+SUM
      RETURN
C     MEDIUM SPEED PRODUCT FOR NIRREG .LE. NROWS/2
  200 IF (NIRREG .GT. NROWS/2) GO TO 201
      DO 105 NN=1,NROWM
      IP1=NN+1
```

```
      KST=NCOL(NN)
      INDEX=INDEX+NN-KST
      SUM=0.0
      DO 106 KPL=KST,NN
      IJ=INDEX+KPL
106   SUM=SUM+SQVCT(IJ)*RWVCT(KPL)
      NCK=0
      JNDEX=IJ
107   DO 108 KPL=IP1,NROWS
      IF(NN .LT. NCOL(KPL)) GO TO 109
      JNDEX=JNDEX+KPL-NCOL(KPL)
108   SUM=SUM+SQVCT(JNDEX)*RWVCT(KPL)
      GO TO 105
109   NCK=NCK+1
      IF (NCK .GT.NIRREG) GO TO 105
      IF (KPL .GE. KROW(NCK)) GO TO 109
      IP1=KROW(NCK)
      JNDEX=NDEX(NCK)+NN
      GO TO 107
105   ACC(NN)=ACC(NN)+SUM
      GO TO 104
201   DO 503 NN=1,NROWM
      IP1=NN+1
      K=NCOL(NN)
      INDEX=INDEX+NN-K
      SUM=0.0
      DO 502 KRX=K,NN
      IJ=INDEX+KRX
502   SUM=SUM+SQVCT(IJ)*RWVCT(KRX)
      JNDEX=IJ
      DO 504 KRX=IP1,NROWS
      K=NCOL(KRX)
      JNDEX=JNDEX+KRX-K
      IF (NN .LT. K) GO TO 504
      SUM=SUM+SQVCT(JNDEX)*RWVCT(KRX)
504   CONTINUE
```

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```
503   ACC(NN)=ACC(NN)+SUM
      GO TO 104
      END
```

```
      SUBROUTINE QREM(AL,AXG,AWG,SPRIN)
C     TO FIND EFFECTIVE STIFFNESS MATRIX DUE TO ELASTIC RESTRAINTS
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION DUMMY(8)
      DIMENSION AL(1),AXG(1),AWG(1),BNG(51),SPRIN(1)
     *,ELR(8,8),ELRR(8,8),ELRP(8,8),A(8,8),LMI(8),MMI(8)
      COMMON/MAT/YOUNG(3,6),DS(3,6),SNC(3,5,6),NSFL(3,6),P(3,6),NLAY
      COMMON /FG/ IK,IKK,ICP,LREF,NOGA,NFL,NI,ICOL(205),INUM(205)
     *,NBCOND,NBC(7),NODEB(7),KROW(8),NDEX(8),NIRREG
      COMMON/FC/ Y(51),Z(51),ANG(51),H(51,3)
      COMMON /ELFU/ FQREF(205),REX(4),NQR,NORP,NORU
     *,NREL(4),NRST(4),NREU(4)
      COMMON/BOUN/ YK(51),NBCONB,NBCB(7),NODBB(7),MK(51),ROT(5,2)
     *,XDIST(6),DROT(50),NODP(6)
      COMMON /TAM/ MKE(51)
      COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      COMMON /BR/ NVEC(51,2), LMT(51)
      SIN(Q)=DSIN(Q)
      COS(Q)=DCOS(Q)
      ATAN(Q)=DATAN(Q)
      ABS(Q)=DABS(Q)
      SQRT(Q)=DSQRT(Q)
777   FORMAT(/,10X,'THE VALUE OF THE TANGENTIAL SPRING CONSTANT IS =',E1
     *5.6,/,10X,'THE VALUE OF THE RADIAL SPRING CONSTANT IS =',E15.6,/,
     *10X,'THE VALUE OF THE TORSIONAL SPRING CONSTANT IS =',E15.6,/)
      IF (NORP .EQ. 0) GO TO 1
      READ(MREAD,2)SCTP,SCTY,SCRP,(NREL(I),REX(I),I=1,NORP)
    2 FORMAT(3D15.6/(4(I5,D15.6)))
      WRITE(MWRITE,1100) NORP
 1100 FORMAT(//,' THE CONSTANTS FOR',I3,' ELASTIC POINT CONSTRAINTS ARE
     @:')
      WRITE(MWRITE,777)SCTP,SCTY,SCRP
      WRITE(MWRITE,1140)
 1140 FORMAT(/,10X,'ELEMENT',10X,'S COORDINATE')
      WRITE(MWRITE,1145) (NREL(I),REX(I),I=1,NORP)
 1145 FORMAT(' ',10X,I3,13X,D13.6)
```

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```
      DO 10 IQ=1,NORP                                                   QREM0370
      SL=REX(IQ)                                                        QREM0380
      NE=NREL(IQ)                                                       QREM0390
     L= MKE(NE) -1                                                      QREM0400
     K1 = NVEC(NE,1)                                                    QREM0410
     K2 = NVEC(NE,2)                                                    QREM0420
     P5=Z(K2)-Z(K1)                                                     QREM0430
     P6=Y(K2)-Y(K1)                                                     QREM0440
      P7=ANG(K2   )-ANG(K1)                                             QREM0450
     IF(YK(NE).EQ.1.0)  P7=ANG(K2)  - ROT(L,2)-ANG(K1)                  QREM0460
     IF(YK(NE).EQ.1.0.AND.ROT(L,1).EQ.0.0)  P7=ROT(L,2)+ANG(K2)-ANG(K1) QREM0470
     IF(YK(NE).EQ.2.0)   P7= ANG(K2)- DROT(NE)  - ANG(K1)               QREM0480
     IF(YK(NE).EQ.3.0)  P7=ROT(L,2)+ANG(K2)-DROT(NE)-ANG(K1)            QREM0490
     PIE= 3.141592653589793D+00                                         QREM0500
     PIE2= 2.0*PIE                                                      QREM0510
     PIE32= 1.5 *PIE                                                    QREM0520
     ANG2=ANG(K2)                                                       QREM0530
     ANG1=ANG(K1)                                                       QREM0540
     IF(YK(NE).EQ.1.0.AND.ROT(L,1).EQ.0.0)ANG(K2)=ROT(L,2)+ANG(K2)      QREM0550
     IF(YK(NE).EQ.1.0.AND.ROT(L   ,1).EQ.1.0)ANG(K1)=ROT(L   ,2)+ANG(K1) QREM0560
     IF(YK(NE).EQ.2.0)  ANG(K1)= DROT(NE)  + ANG(K1)                    QREM0570
     IF(YK(NE).EQ.3.0)  ANG(K2)= ROT(L,2)+ANG(K2)                       QREM0580
     IF(YK(NE).EQ.3.0)   ANG(K1)= DROT(NE)  + ANG  (K1)                 QREM0590
     APHA = PIE / 2.0                                                   QREM0600
     IF(P5.LT.0.0)  APHA= -APHA                                         QREM0610
     IF(P6.NE.0.0)  APHA= ATAN(P5/P6)                                   QREM0620
     IF(P6.LT.0.0.AND.P5.LT.0.0)APHA=APHA-PIE                           QREM0630
      IF(P6.LT.0.0 .AND. P5.GE.0.0)  APHA=APHA+PIE                      QREM0640
      BNG(NE+1)=ANG(K2   )                                              QREM0650
      BNG(NE)=ANG(K1)                                                   QREM0660
     IF(P7.GT.(PIE32 ).AND.APHA.LT.0.0)  BNG(NE+1)=ANG(K2)   -PIE2      QREM0670
     IF(P7.GT.(PIE32 ).AND.APHA.GT.0.0)  BNG(NE)=ANG(K1)+PIE2           QREM0680
     IF(P7.LT.(-PIE32).AND.APHA.GT.0.0)  BNG(NE+1)=ANG(K2)  +PIE2       QREM0690
     IF(P7.LT.(-PIE32).AND.APHA.LT.0.0)  BNG(NE)=ANG(K1)-PIE2           QREM0700
      BZER=BNG(NE)-APHA                                                 QREM0710
      B1=(-2.*BNG(NE+1)-4.*BNG(NE)+6.*APHA)/AL(NE)                      QREM0720
```

```
      B2=(3.*BNG(NE+1)+3.*BNG(NE)-6.*APHA)/AL(NE)**2
     ANG(K2)= ANG2
     ANG(K1)= ANG1
      DO 400 I=1,8
      DO 400 J=1,8
400   A(I,J)=0.0
      A(1,1)= COS(BNG(NE)-APHA)
      A(1,2)= SIN(BNG(NE)-APHA)
      A(2,1)=-SIN(BNG(NE)-APHA)
      A(2,2)= COS(BNG(NE)-APHA)
      A(3,3)=1.
      A(5,1)=COS(BNG(NE+1)-APHA)
      A(5,2)=SIN(BNG(NE+1)-APHA)
      A(5,3)=P6*SIN(BNG(NE+1))-P5*COS(BNG(NE+1))
      A(6,1)=-SIN(BNG(NE+1)-APHA)
      A(6,2)=COS(BNG(NE+1)-APHA)
      A(6,3)=P6*COS(BNG(NE+1))+P5*SIN(BNG(NE+1))
      A(7,3)=1.
      A(4,4)=1.
      A(5,4)=AL(NE)
      A(5,7)=AL(NE)**2
      A(5,8)=AL(NE)**3
      A(6,5)=AL(NE)**2
      A(6,6)=AL(NE)**3
      P8=B1+2.*B2*AL(NE)
      A(7,4)=AL(NE)*P8
      A(7,5)=2.*AL(NE)
      A(7,6)=3.*AL(NE)**2
      A(7,7)=AL(NE)**2*P8
      A(7,8)=AL(NE)**3*P8
      A(8,4)=1.
      A(8,5)=-AL(NE)**2*P8
      A(8,6)=-AL(NE)**3*P8
      A(8,7)=2.*AL(NE)
      A(8,8)=3.*AL(NE)**2
      CALL MINV(A,8,DET,LMI,MMI)
```


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      PHI=BZER+B1*SL+B2*SL**2                                           QREM1090
      PHIP=B1+2.*B2*SL                                                  QREM1100
      YZET=0.0                                                          QREM1110
      ZZET=0.0                                                          QREM1120
      DO 104 JJ=1,NOGA                                                  QREM1130
      P2=BZER+B1*SL*AXG(JJ)+B2*(SL*AXG(JJ))**2+APHA                     QREM1140
      YZET=YZET+COS(P2)*SL*AWG(JJ)                                      QREM1150
  104 ZZET=ZZET+SIN(P2)*SL*AWG(JJ)                                      QREM1160
      P3=YZET*SIN(PHI+APHA)-ZZET*COS(PHI+APHA)                          QREM1170
      P4=YZET*COS(PHI+APHA)+ZZET*SIN(PHI+APHA)                          QREM1180
      ELR(1,1)=SCTP*COS(PHI)**2+SCTY*SIN(PHI)**2                        QREM1190
      ELR(2,1)= (SCTP-SCTY)*COS(PHI)*SIN(PHI)                           QREM1200
      ELR(3,1)=P3*COS(PHI)*SCTP-P4*SIN(PHI)*SCTY                        QREM1210
      ELR(4,1)=SL*COS(PHI)*SCTP                                         QREM1220
      ELR(5,1)=-SL**2*SIN(PHI)*SCTY                                     QREM1230
      ELR(6,1)=-SL**3*SIN(PHI)*SCTY                                     QREM1240
      ELR(7,1)=SL**2*COS(PHI)*SCTP                                      QREM1250
      ELR(8,1)=SL**3*COS(PHI)*SCTP                                      QREM1260
      ELR(2,2)=SCTP*SIN(PHI)**2+SCTY*COS(PHI)**2                        QREM1270
      ELR(3,2)=P3*SIN(PHI)*SCTP+P4*COS(PHI)*SCTY                        QREM1280
      ELR(4,2)=SL*SIN(PHI)*SCTP                                         QREM1290
      ELR(5,2)=SL**2*COS(PHI)*SCTY                                      QREM1300
      ELR(6,2)=SL**3*COS(PHI)*SCTY                                      QREM1310
      ELR(7,2)=SL**2*SIN(PHI)*SCTP                                      QREM1320
      ELR(8,2)=SL**3*SIN(PHI)*SCTP                                      QREM1330
      ELR(3,3)=P3**2*SCTP+P4**2*SCTY+SCRP                               QREM1340
      ELR(4,3)=P3*SI*SCTP+SL*PHIP*SCRP                                  QREM1350
      ELR(5,3)=P4*SL**2*SCTY+2.*SL*SCRP                                 QREM1360
      ELR(6,3)=P4*SL**3*SCTY+3.*SL**2*SCRP                              QREM1370
      ELR(7,3)=(P3*SCTP+PHIP*SCRP)*SL**2                                QREM1380
      ELR(8,3)=(P3*SCTP+PHIP*SCRP)*SL**3                                QREM1390
      ELR(4,4)=(SCTP+PHIP**2*SCRP)*SL**2                                QREM1400
      ELR(5,4)=2.*SL**2*PHIP*SCRP                                       QREM1410
      ELR(6,4)=3.*SL**3*PHIP*SCRP                                       QREM1420
      ELR(7,4)=(SCTP+PHIP**2*SCRP)*SL**3                                QREM1430
      ELR(8,4)=(SCTP+PHIP**2*SCRP)*SL**4                                QREM1440
```

```
      ELR(5,5)=SL**4*SCTY+4.*SL**2*SCRP
       ELR(6,5)=SL**5*SCTY+6.*SL**3*SCRP
       ELR(7,5)=2.*SL**3*PHIP*SCRP
       ELR(8,5)=2.*SL**4*PHIP*SCRP
      ELR(6,6)=SL**6*SCTY+9.*SL**4*SCRP
       ELR(7,6)=3.*SL**4*PHIP*SCRP
       ELR(8,6)=3.*SL**5*PHIP*SCRP
       ELR(7,7)=(SCTP+PHIP**2*SCRP)*SL**4
       ELR(8,7)=(SCTP+PHIP**2*SCRP)*SL**5
       ELR(8,8)=(SCTP+PHIP**2*SCRP)*SL**6
       DO 12 I=1,7
       IP1=I+1
       DO 12 J=IP1,8
12     ELR(I,J)=ELR(J,I)
       DO 13 I=1,8
       DO 13 J=1,8
       ELRR(I,J)=0.0
       DO 13 K=1,8
13     ELRR(I,J)=ELPR(I,J)+ELR(I,K)*A(K,J)
       DO 14 I=1,8
       DO 14 J=1,8
       ELRP(I,J)=0.0
       DO 14 K=1,8
14     ELRP(I,J)=ELRP(I,J)+A(K,I)*ELRR(K,J)
      IF(YK(NE).EQ.0.0) GOTO   201
      CALL ROTAT(3,ELRP,DUMMY,NE)
 201  CONTINUE
       CALL ASSEM(NE,IK,ELRP,SPRIN,ICP,INUM)
10     CONTINUE
1      IF(NORU .EQ.0) GO TO 4
       READ(MREAD,3) SCTU,SCTW,SCRU,(NRST(I),NREU(I),I=1,NORU)
    3 FORMAT(3D15.6/(8I5))
      WRITE(MWRITE,1120) NORU
1120  FORMAT(//,' THE CONSTANTS FOR',I3,'  ELASTIC FOUNDATIONS ARE:')
      WRITE(MWRITE,777)SCTU,SCTW,SCRU
      WRITE(MWRITE,1150)
```

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1150 FORMAT(/,10X,'FIRST ELEMENT',10X,'NUMBER OF ELEMENTS')            QREM1810
     WRITE(MWRITE,1155) (NRST(I),NREU(I),I=1,NORU)                       QREM1820
1155 FORMAT(' ',13X,I3,24X,I3)                                            QREM1830
      DO 15 IQ=1,NORU                                                     QREM1840
      NSTAT=NRST(IQ)                                                      QREM1850
      NEND=NREU(IQ)                                                       QREM1860
      DO 16 IR=1,NEND                                                     QREM1870
      NE=(NSTAT-1)+IR                                                     QREM1880
      IF(NE .GT. IK) NE=NE-IK                                             QREM1890
     L= MKE(NE) -1                                                        QREM1900
     K1 = NVEC(NE,1)                                                      QREM1910
     K2 = NVEC(NE,2)                                                      QREM1920
     P5=Z(K2)-Z(K1)                                                       QREM1930
     P6=Y(K2)-Y(K1)                                                       QREM1940
      P7=ANG(K2  )-ANG(K1)                                                QREM1950
     IF(YK(NE).EQ.1.0) P7=ANG(K2) - ROT(L,2)-ANG(K1)                      QREM1960
     IF(YK(NE).EQ.1.0.AND.ROT(L,1).EQ.0.0) P7=ROT(L,2)+ANG(K2)-ANG(K1)   QREM1970
     IF(YK(NE).EQ.2.0)  P7= ANG(K2)- DROT(NE) - ANG(K1)                   QREM1980
     IF(YK(NE).EQ.3.0) P7=ROT(L,2)+ANG(K2)-DROT(NE)-ANG(K1)               QREM1990
     PIE= 3.141592653589793D+00                                           QREM2000
     PIE2= 2.0*PIE                                                        QREM2010
     PIE32= 1.5 *PIE                                                      QREM2020
     ANG2=ANG(K2)                                                         QREM2030
     ANG1=ANG(K1)                                                         QREM2040
     IF(YK(NE).EQ.1.0.AND.ROT(L,1).EQ.0.0)ANG(K2)=ROT(L,2)+ANG(K2)        QREM2050
     IF(YK(NE).EQ.1.0.AND.ROT(L  ,1).EQ.1.0)ANG(K1)=ROT(L  ,2)+ANG(K1)    QREM2060
     IF(YK(NE).EQ.2.0) ANG(K1)= DROT(NE) + ANG(K1)                        QREM2070
     IF(YK(NE).EQ.3.0) ANG(K2)= ROT(L,2)+ANG(K2)                          QREM2080
     IF(YK(NE).EQ.3.0)  ANG(K1)= DROT(NE) + ANG (K1)                      QREM2090
     APHA = PIE / 2.0                                                     QREM2100
     IF(P5.LT.0.0) APHA= -APHA                                            QREM2110
     IF(P6.NE.0.0) APHA= ATAN(P5/P6)                                      QREM2120
     IF(P6.LT.0.0.AND.P5.LT.0.0)APHA=APHA-PIE                             QREM2130
      IF(P6.LT.0.0 .AND. P5.GE.0.0) APHA=APHA+PIE                         QREM2140
      BNG(NE+1)=ANG(K2  )                                                 QREM2150
      BNG(NE)=ANG(K1)                                                     QREM2160
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      IF(P7.GT.(PIE32 ).AND.APHA.LT.0.0) BNG(NE+1)=ANG(K2)   -PIE2
      IF(P7.GT.(PIE32 ).AND.APHA.GT.0.0) BNG(NE)=ANG(K1)+PIE2
      IF(P7.LT.(-PIE32 ).AND.APHA.GT.0.0) BNG(NE+1)=ANG(K2)   +PIE2
      IF(P7.LT.(-PIE32 ).AND.APHA.LT.0.0) BNG(NE)=ANG(K1)-PIE2
       BZER=BNG(NE)-APHA
       B1=(-2.*BNG(NE+1)-4.*BNG(NE)+6.*APHA)/AL(NE)
       B2=(3.*BNG(NE+1)+3.*BNG(NE)-6.*APHA)/AL(NE)**2
      ANG(K2)= ANG2
      ANG(K1)= ANG1
       DO 401 I=1,8
       DO 401 J=1,8
401    A(I,J)=0.0
       A(1,1)= COS(BNG(NE)-APHA)
       A(1,2)= SIN(BNG(NE)-APHA)
       A(2,1)=-SIN(BNG(NE)-APHA)
       A(2,2)= COS(BNG(NE)-APHA)
       A(3,3)=1.
       A(5,1)=COS(BNG(NE+1)-APHA)
       A(5,2)=SIN(BNG(NE+1)-APHA)
       A(5,3)=P6*SIN(BNG(NE+1))-P5*COS(BNG(NE+1))
       A(6,1)=-SIN(BNG(NE+1)-APHA)
       A(6,2)=COS(BNG(NE+1)-APHA)
       A(6,3)=P6*COS(BNG(NE+1))+P5*SIN(BNG(NE+1))
       A(7,3)=1.
       A(4,4)=1.
       A(5,4)=AL(NE)
       A(5,7)=AL(NE)**2
       A(5,8)=AL(NE)**3
       A(6,5)=AL(NE)**2
       A(6,6)=AL(NE)**3
       P8=B1+2.*B2*AL(NE)
       A(7,4)=AL(NE)*P8
       A(7,5)=2.*AL(NE)
       A(7,6)=3.*AL(NE)**2
       A(7,7)=AL(NE)**2*P8
       A(7,8)=AL(NE)**3*P8
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      A(8,4)=1.                                                         QREM2530
      A(8,5)=-AL(NE)**2*P8                                              QREM2540
      A(8,6)=-AL(NE)**3*P8                                              QREM2550
      A(8,7)=2.*AL(NE)                                                  QREM2560
      A(8,8)=3.*AL(NE)**2                                               QREM2570
      CALL MINV(A,8,DET,LMI,MMI)                                        QREM2580
      DO 102 I=1,8                                                      QREM2590
      DO 102 J=1,8                                                      QREM2600
  102  ELR(I,J)=0.0                                                     QREM2610
      DO 103 J=1,NOGA                                                   QREM2620
      ZET=AL(NE)*AXG(J)                                                 QREM2630
      PHIP=B1+2.*B2*ZET                                                 QREM2640
      PHI=BZER+B1*ZET+B2*ZET**2                                         QREM2650
      WET=AL(NE)*AWG(J)                                                 QREM2660
      YZET=0.0                                                          QREM2670
      ZZET=0.0                                                          QREM2680
      DO 105 JJ=1,NOGA                                                  QREM2690
      P2=BZER+B1*ZET*AXG(JJ)+B2*(ZET*AXG(JJ))**2+APHA                   QREM2700
      YZET=YZET+COS(P2)*ZET*AWG(JJ)                                     QREM2710
  105 ZZET=ZZET+SIN(P2)*ZET*AWG(JJ)                                     QREM2720
      P3=YZET*SIN(PHI+APHA)-ZZET*COS(PHI+APHA)                          QREM2730
      P4=YZET*COS(PHI+APHA)+ZZET*SIN(PHI+APHA)                          QREM2740
     ELR(1,1)=ELR(1,1)+(SCTU*COS(PHI)**2+SCTW*SIN(PHI)**2)*WET          QREM2750
     ELR(2,1)=ELR(2,1)+((SCTU-SCTW)*SIN(PHI)*COS(PHI))*WET              QREM2760
     ELR(3,1)=ELR(3,1)+(P3*SCTU*COS(PHI)-P4*SCTW*SIN(PHI))*WET          QREM2770
     ELR(5,1)=ELR(5,1)-(ZET**2*SCTW*SIN(PHI))*WET                       QREM2780
     ELR(6,1)=ELR(6,1)-(ZET**3*SCTW*SIN(PHI))*WET                       QREM2790
     ELR(2,2)=ELR(2,2)+(SCTU*SIN(PHI)**2+SCTW*COS(PHI)**2)*WET          QREM2800
     ELR(3,2)=ELR(3,2)+(P3*SCTU*SIN(PHI)+P4*SCTW*COS(PHI))*WET          QREM2810
     ELR(5,2)=ELR(5,2)+(ZET**2*SCTW*COS(PHI))*WET                       QREM2820
     ELR(6,2)=ELR(6,2)+(ZET**3*SCTW*COS(PHI))*WET                       QREM2830
     ELR(3,3)=ELR(3,3)+(P3**2*SCTU+P4**2*SCTW+SCRU)*WET                 QREM2840
     ELR(5,3)=ELR(5,3)+(P4*SCTW*ZET**2+2.0*SCRU*ZET)*WET                QREM2850
     ELR(6,3)=ELR(6,3)+(P4*SCTW*ZET**3+3.0*SCRU*ZET**2)*WET             QREM2860
     ELR(5,5)=ELR(5,5)+(ZET**4*SCTW+4.0*ZET**2*SCRU)*WET                QREM2870
     ELR(6,5)=ELR(6,5)+(ZET**5*SCTW+6.0*ZET**3*SCRU)*WET                QREM2880
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```
      ELR(6,6)=ELR(6,6)+(ZET**6*SCTW+9.0*ZET**4*SCRU)*WET               QREM2890
       ELR(4,1)=ELR(4,1)+ZET*COS(PHI)*SCTU*WET                          QREM2900
       ELR(7,1)=ELR(7,1)+ZET**2*COS(PHI)*SCTU*WET                       QREM2910
       ELR(8,1)=ELR(8,1)+ZET**3*COS(PHI)*SCTU*WET                       QREM2920
       ELR(4,2)=ELR(4,2)+ZET*SIN(PHI)*SCTU*WET                          QREM2930
       ELR(7,2)=ELR(7,2)+ZET**2*SIN(PHI)*SCTU*WET                       QREM2940
       ELR(8,2)=ELR(8,2)+ZET**3*SIN(PHI)*SCTU*WET                       QREM2950
       ELR(4,3)=ELR(4,3)+(P3*SCTU+PHIP*SCRU)*ZET*WET                    QREM2960
       ELR(7,3)=ELR(7,3)+(P3*SCTU+PHIP*SCRU)*ZET**2*WET                 QREM2970
       ELR(8,3)=ELR(8,3)+(P3*SCTU+PHIP*SCRU)*ZET**3*WET                 QREM2980
       ELR(4,4)=ELR(4,4)+(SCTU+PHIP**2*SCRU)*ZET**2*WET                 QREM2990
       ELR(5,4)=ELR(5,4)+2.*ZET**2*PHIP*SCRU*WET                        QREM3000
       ELR(6,4)=ELR(6,4)+3.*ZET**3*PHIP*SCRU*WET                        QREM3010
       ELR(7,4)=ELR(7,4)+(SCTU+PHIP**2*SCRU)*ZET**3*WET                 QREM3020
       ELR(8,4)=ELR(8,4)+(SCTU+PHIP**2*SCRU)*ZET**4*WET                 QREM3030
       ELR(7,5)=ELR(7,5)+2.*ZET**3*PHIP*SCRU*WET                        QREM3040
       ELR(8,5)=ELR(8,5)+2.*ZET**4*PHIP*SCRU*WET                        QREM3050
       ELR(7,6)=ELR(7,6)+3.*ZET**4*PHIP*SCRU*WET                        QREM3060
       ELR(8,6)=ELR(8,6)+3.*ZET**5*PHIP*SCRU*WET                        QREM3070
       ELR(7,7)=ELR(7,7)+(SCTU+PHIP**2*SCRU)*ZET**4*WET                 QREM3080
       ELR(8,7)=ELR(8,7)+(SCTU+PHIP**2*SCRU)*ZET**5*WET                 QREM3090
       ELR(8,8)=ELR(8,8)+(SCTU+PHIP**2*SCRU)*ZET**6*WET                 QREM3100
  103  CONTINUE                                                         QREM3110
       DO 5 I=1,7                                                       QREM3120
       IP1=I+1                                                          QREM3130
       DO 5 J=IP1,8                                                     QREM3140
    5  ELR(I,J)=ELR(J,I)                                                QREM3150
       DO 6 I=1,8                                                       QREM3160
       DO 6 J=1,8                                                       QREM3170
       ELRR(I,J)=0.0                                                    QREM3180
       DO 6 K=1,8                                                       QREM3190
    6  ELRR(I,J)=ELRR(I,J)+ELR(I,K)*A(K,J)                              QREM3200
       DO 7 I=1,8                                                       QREM3210
       DO 7 J=1,8                                                       QREM3220
       ELRP(I,J)=0.0                                                    QREM3230
       DO 7 K=1,8                                                       QREM3240
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7       ELRP(I,J)=ELRP(I,J)+A(K,I)*ELRR(K,J)                          QREM3250
      IF(YK(NE).EQ.0.0) GOTO   202                                      QREM3260
      CALL ROTAT(3,ELRP,DUMMY,NE)                                       QREM3270
  202 CONTINUE                                                          QREM3280
16     CALL ASSEM(NE,IK,ELRP,SPRIN,ICP,INUM)                            QREM3290
15     CONTINUE                                                         QREM3300
    4 RETURN                                                            QREM3310
      END                                                               QREM3320
```

```
      SUBROUTINE ROTAT(IND,ELM,ELV,IR)                                  ROTA0010
C     THIS SUBROUTINE TRANSFORMS MATRICES FROM ELEMENT  SYSTEMS TO THE  ROTA0020
C     GLOBAL SYSTEM AND VICE-VERSA.   IND = 1 FOR  GLOBAL VECTOR INTO   ROTA0030
C     ELEMENT VECTOR, IND=2 FOR ELEMEMT VECTOR INTO GLOBAL VECTOR, IND = 3ROTA0040
C     FOR ELEMENT MATRIX INTO GLOBAL SYSTEM                             ROTA0050
C     ELM IS THE MATRIX TO BE TRANSFORMED, ELV IS THE VECTOR TO BE      ROTA0060
C     TRANSFORMED, WHILE IR IS THE ELEMENT NUMBER   YK,ROT,AND DROT USED ROTA0070
C     BELOW, INDICATE WHETHER A BRANCH OR A DISCONTINUITY IS BEING CON- ROTA0080
C     SIDERED AND WHAT THE ANGLE OF ROTATION IS.                        ROTA0090
      IMPLICIT REAL*8(A-H,O-Z)                                          ROTA0100
      DIMENSION ELM(8,8),ELV(8),TR(4,4),TRAN(8,8),WORK(8),ELRR(8,8)     ROTA0110
      COMMON /BOUN/ YK(51),NBCONB,NBCB(7),NODBB(7),MK(51),RCT(5,2)      ROTA0120
     *,XDIST(6),DROT(50),NODP(6)                                        ROTA0130
      COMMON /TAM/ MKE(51)                                              ROTA0140
      COMMON /BR/ NVEC(51,2), IMT(51)                                   ROTA0150
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH                                ROTA0160
      COMMON /TIME/  IT                                                 ROTA0170
      SIN(Q)=DSIN(Q)                                                    ROTA0180
      COS(Q)=DCOS(Q)                                                    ROTA0190
      ATAN(Q)=DATAN(Q)                                                  ROTA0200
      ABS(Q)=DABS(Q)                                                    ROTA0210
      SQRT(Q)=DSQRT(Q)                                                  ROTA0220
      DO 1100 I=1,4                                                     ROTA0230
      DO 1100 J = 1,4                                                   ROTA0240
 1100 TR(I,J)  = 0.0                                                    ROTA0250
      TR(3,3)  = 1.0                                                    ROTA0260
      TR(4,4)  = 1.0                                                    ROTA0270
      MOP = MKE(IR)  -1                                                 ROTA0280
      DO 1110 J = 1,8                                                   ROTA0290
      DO 1110 K = 1,8                                                   ROTA0300
 1110 TRAN(J,K)  = 0.0                                                  ROTA0310
      DO 1115 J= 1,8                                                    ROTA0320
 1115 TRAN(J,J)  = 1.0                                                  ROTA0330
      ANGK= DROT(IR)                                                    ROTA0340
      IF(YK(IR).EQ.1.0.OR.YK(IR).EQ.3.0) ANGK=ROT(MOP,2)                ROTA0350
      TR(1,1)  = DCOS(ANGK)                                             ROTA0360
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      TR(1,2)  = DSIN(ANGK)                                          ROTA0370
      TR(2,1)  = -DSIN(ANGK)                                         ROTA0380
      TR(2,2)  = DCOS(ANGK)                                          ROTA0390
      IF(YK(IR).EQ.2.0)  GO TO  1120                                 ROTA0400
      IF  (ROT(MOP,1).NE.0.0)  GO TO 1120                            ROTA0410
      DO 1130 J = 5,8                                                ROTA0420
      DO 1130 K = 5,8                                                ROTA0430
 1130 TRAN(J,K)  = TR(J-4,K-4)                                       ROTA0440
      TRAN(5,7)  = XDIST(MOP)* TR(1,1)                               ROTA0450
      TRAN(6,7)  = XDIST(MOP)  * TR(2,1)                             ROTA0460
      GOTO 1150                                                      ROTA0470
 1120 DO 1140 J = 1,4                                                ROTA0480
      DO 1140 K = 1,4                                                ROTA0490
 1140 TRAN(J,K)  = TR(J,K)                                           ROTA0500
      IF(YK(IR).EQ.2.0)  GO TO  1150                                 ROTA0510
      TRAN(1,3)  = XDIST(MOP)* TR(1,1)                               ROTA0520
      TRAN(2,3)  = XDIST(MOP)  * TR(2,1)                             ROTA0530
 1150 CONTINUE                                                       ROTA0540
      IF(YK(IR).NE.3.0)  GOTO 3000                                   ROTA0550
      ANGZ=DROT(IR)                                                  ROTA0560
      TRAN(1,1)  = DCOS(ANGZ)                                        ROTA0570
      TRAN(1,2)  = DSIN(ANGZ)                                        ROTA0580
      TRAN(2,1)  = -DSIN(ANGZ)                                       ROTA0590
      TRAN(2,2)  = DCOS(ANGZ)                                        ROTA0600
 3000 CONTINUE                                                       ROTA0610
      IF(IND.EQ.3)  GOTO 800                                         ROTA0620
      IF(IND.EQ.1)   GOTO 100                                        ROTA0630
      DO 210 I=1,8                                                   ROTA0640
      DO 210 J=1,8                                                   ROTA0650
  210 ELRR(I,J)  = TRAN(J,I)                                         ROTA0660
      DO 215 I=1,8                                                   ROTA0670
      DO 215 J= 1,8                                                  ROTA0680
  215 TRAN(I,J)  = ELRR(I,J)                                         ROTA0690
  100 CONTINUE                                                       ROTA0700
  110 CONTINUE                                                       ROTA0710
      DO 1160 I = 1,8                                                ROTA0720
```

```
      WORK(I) = 0.0                                                     ROTA0730
      DO 1160 J = 1,8                                                   ROTA0740
 1160 WORK(I) = WORK(I) + TRAN(I,J) * ELV(J)                            ROTA0750
      DO 1170 I= 1,8                                                    ROTA0760
 1170 ELV(I) = WORK(I)                                                  ROTA0770
      RETURN                                                            ROTA0780
  800 CONTINUE                                                          ROTA0790
      DO 2160 I = 1,8                                                   ROTA0800
      DO 2160 J = 1,8                                                   ROTA0810
      ELRR(I,J) = 0.0                                                   ROTA0820
      DO 2160 K = 1,8                                                   ROTA0830
 2160 ELRR(I,J) = ELRR(I,J) + FLM(I,K)*TRAN(K,J)                        ROTA0840
      DO 2170 I= 1,8                                                    ROTA0850
      DO 2170 J= 1,8                                                    ROTA0860
      ELM(I,J) = 0.0                                                    ROTA0870
      DO 2170 K = 1,8                                                   ROTA0880
 2170 ELM(I,J) = ELM(I,J) + TRAN(K,I) * ELRR(K,J)                       ROTA0890
      RETURN                                                            ROTA0900
      END                                                               ROTA0910
```


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```
      SUBROUTINE SOLV (STIFM,G,SOL,NCOL,KROW,NDEX,NROWS,NIRREG)
C     SOLVE (LL*)(SOL)=(FORCE) FOR DISPLACEMENTS (SOL)
       IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION STIFM(1),G(1),SOL(1), NCOL(1),KROW(1),NDEX(1)
C     INTERMEDIATE SOLUTION USING THE LOWER TRIANGLE
  100 INDEX=0
      SOL(1)=G(1)
      DO 104 I=2,NROWS
      IM1=I-1
      SUM=0.0
      K=NCOL(I)
      INDEX=INDEX+I-K
      IF (IM1-K) 103,101,101
  101 DO 102 J=K,IM1
      IJ=INDEX+J
      SU=SOL(J)
  102 SUM=SUM+STIFM(IJ)*SU
  103 II=INDEX+I
  104 SOL(I)= G(I)-SUM
C     SOL CONTAINS THE INTERMEDIATE SOLUTION
C     COMPLETE THE SOLUTION USING THE UPPER TRIANGLE
      SOL(NROWS)=SOL(NROWS)/STIFM(II)
      INDEX=INDEX-NROWS+NCOL(NROWS)
      IF (NIRREG .GT. 0) GO TO 111
      DO 109 KK=2,NROWS
      I=NROWS+1-KK
      IP1=I+1
      SUM=0.0
      JNDEX=INDEX+I
      DO 107 J=IP1,NROWS
      K=NCOL(J)
      IF (I-K) 108,106,106
  106 JNDEX=JNDEX+J-K
      SU=SOL(J)
  107 SUM=SUM+STIFM(JNDEX)*SU
  108 II=INDEX+I
```

```
      SOL(I)= SOL(I)/STIFM (II)-SUM
  109 INDEX=INDEX-I+NCOL(I)
      RETURN
  111 IF (NIRREG-NROWS /2) 116,116,112
C     TOO MANY IRREGULAR ROWS FOR ACCELERATED SOLUTION
  112 DO 115 KK=2,NROWS
      I=NROWS+1-KK
      IP1=I+1
      JNDEX=INDEX+I
      SUM=0.0
      JNDEX=INDEX+I
      DO 114 J=IP1,NROWS
      K=NCOL(J)
      JNDEX=JNDEX+J-K
      IF (I-K) 114,113,113
 113  SU=SOL(J)
      SUM=SUM+STIFM(JNDEX)*SU
  114 CONTINUE
      II=INDEX+I
      SOL(I)= SOL(I)/STIFM(II) -SUM
  115 INDEX=INDEX-I+NCOL(I)
      RETURN
C     ACCELERATED SOLUTION FOR CASE WITH IRREGULAR ROWS
  116 DO 125 KK=2,NRCWS
      I=NROWS+1-KK
      IP1=I+1
      SUM=0.0
      NCK=0
       JNDEX=INDEX+I
  117 DO 119 J=IP1,NROWS
      K=NCOL(J)
      IF (I-K) 120,118,118
  118 JNDEX=JNDEX+J-K
      SU=SOL(J)
  119 SUM=SUM+STIFM(JNDEX)*SU
      GO TO 124
```

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```
120 NCK=NCK+1                                                            SOLV0730
    IF (NIRREG-NCK) 124,121,121                                          SOLV0740
121 IP1=KROW(NCK)                                                        SOLV0750
    IF (I-NCOL(IP1)) 120,122,122                                         SOLV0760
122 IF (IP1-J) 120,123,123                                               SOLV0770
123 JNDEX=NDEX(NCK)+I                                                    SOLV0780
    GO TO 117                                                            SOLV0790
124 II=INDEX+I                                                           SOLV0800
    SOL(I)= SOL(I)/STIFM(II) -SUM                                        SOLV0810
125 INDEX=INDEX-I+NCOL(I)                                                SOLV0820
    RETURN                                                               SOLV0830
    END                                                                  SOLV0840
```

```
      SUBROUTINE STRESS(DELTAT,ASFL,GZETA,SNS,SNP,NV1,NV2,NV3)
C       TO EVALUATE GENERALIZED NODAL LOAD VECTOR DUE TO LARGE DEFLECTION
C       AND ELASTIC-PLASTIC STRAIN
        IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION ASFL(NV1,3,NV2,NV3),GZETA(NV1,3,NV2),SNS(NV1,3,NV2,NV3)
     @,SNP(NV1,3,NV2,NV3)
      DIMENSION DISM(8) ,DELM(8), DUMMY(8,8)
        DIMENSION ELFP(8),BEPS(3),CEPS(3,3),BINPW(3),BIMPW(3),HWB(3,3),
     *PN(8),PM(8),HNL(8),BINPP(3),BIMPP(3)
      COMMON /FG/ IK,IKK,ICP,LREF,NOGA,NFL,NI,ICOL(205),INUM(205)
     *,NBCOND,NBC(7),NODEB(7),KROW(8),NDEX(8),NIRREG
        COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      COMMON/MAT/YOUNG(3,6),DS(3,6),SNO(3,5,6),NSFL(3,6),P(3,6),NLAY
      COMMON/VQ/ FLVA(205),DISP(205),DELD(205),BINP(50,3),BIMP(50,3)
        COMMON/BA/ BEP(50,3,3,8),AL(50),AXG(3),AWG(3),WET(50,3),
     *CE1(50,3),CE2(50,3),CE3(50,3),CM1(50,3),CM2(50,3),CM3(50,3)
      COMMON/BOUN/YK(51),NBCONB,NBCB(7),NODBB(7),MK(51),ROT(5,2)
     *,XDIST(6),DROT(50),NODP(6)
      COMMON/BR/ NVEC(51,2), LMT(51)
      COMMON /TAM/ MKE(51)
        ABS(Q)=DABS(Q)
        DO 502 IR=1,IK
      K1= NVEC(IR,1)
      K2= NVEC(IR,2)
      DO 8000 K=1,8
      INDEX= (K1-1)*4+K
      IF(K.GT.4) INDEX= (K2-1)*4+K-4
      DISM(K) = DISP(INDEX)
      DELM(K) = DELD(INDEX)
 8000 CONTINUE
      IF(YK(IR).EQ.0.0) GOTO 1010
           CALL ROTAT(1,DUMMY,DISM,IR)
           CALL ROTAT(1,DUMMY,DELM,IR)
 1010 CONTINUE
      IP=MKE(IR)
      NLAP=NLAY
```


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```
      IF(MKE(IR).GT.1) NLAP=1                                           STRS0370
       DO 503 J=1,NOGA                                                  STRS0380
       BINP(IR,J)=0.                                                    STRS0390
       BIMP(IR,J)=0.                                                    STRS0400
       BINPP(J)=0.0                                                     STRS0410
       BIMPP(J)=0.0                                                     STRS0420
  202  DO 402 I=1,3                                                     STRS0430
       BEPS(I)=0.                                                       STRS0440
       DO 402 K=1,8                                                     STRS0450
  402  BEPS(I)=BEPS(I)+BEP(IR,J,I,K)*DELM(K)                            STRS0460
       DO 403 I=1,3                                                     STRS0470
       CEPS(J,I)=0.0                                                    STRS0480
       DO 403 K=1,8                                                     STRS0490
  403  CEPS(J,I)=CEPS(J,I)+BEP(IR,J,I,K)*DISM(K)                        STRS0500
  205  FARE=BEPS(1)+CEPS(J,2)*BEPS(2)-BEPS(2)**2/2.                     STRS0510
     *+CEPS(J,1)*BEPS(1)-BEPS(1)**2/2.                                  STRS0520
       FCUR=BEPS(3)                                                     STRS0530
      DO 151 M=1,NLAP                                                   STRS0540
      NSFLM= NSFL(M,IP)                                                 STRS0550
       DO 151 N=1,NFL                                                   STRS0560
       K=N+(M-1)*NFL                                                    STRS0570
       BFNP=0.                                                          STRS0580
       BFNPP=0.0                                                        STRS0590
       BEPX=FARE+GZETA(IR,J,K)*FCUR                                     STRS0600
       RFACTR=1.                                                        STRS0610
      IF(DS(M,IP).EQ.0.0) GO TO 1000                                    STRS0620
      S1 = 1.0/P(M,IP)                                                  STRS0630
      S2 = 1.0/DS(M,IP)/DELTAT                                          STRS0640
      RFACTR = 1.0 + (S2*ABS(BEPX))**S1                                 STRS0650
 1000 CONTINUE                                                          STRS0660
       DO 35 L=1,NSFLM                                                  STRS0670
       DESNP=0.0                                                        STRS0680
      SNS(IR,J,K,L) = SNS(IR,J,K,L)+ YOUNG(M,IP)*BEPX                   STRS0690
      SNY=SNO(M,L,IP)*RFACTR                                            STRS0700
       IF(SNS(IR,J,K,L)-SNY) 30,301,20                                  STRS0710
 20    DESNP=SNS(IR,J,K,L)-SNY                                          STRS0720
```

```
      SNS(IR,J,K,L)=SNY                                                 STRS0730
      GO TO 301                                                         STRS0740
   30 IF(SNS(IR,J,K,L)+SNY)40,301,301                                   STRS0750
   40 DESNP=SNS(IR,J,K,L)+SNY                                           STRS0760
      SNS(IR,J,K,L)=-SNY                                                STRS0770
  301 BFNP=BFNP+SNS(IR,J,K,L)*ASFL(IR,J,K,L)                            STRS0780
      SNP(IR,J,K,L)=SNP(IR,J,K,L)+DESNP                                 STRS0790
      BFNPP=BFNPP+SNP(IR,J,K,L)*ASFL(IR,J,K,L)                          STRS0800
   35 CONTINUE                                                          STRS0810
      BINP(IR,J)=BINP(IR,J)+BFNP                                        STRS0820
      BIMP(IR,J)=BIMP(IR,J)+BFNP*GZETA(IR,J,K)                          STRS0830
      BINPP(J)=BINPP(J)+BFNPP                                           STRS0840
      BIMPP(J)=BIMPP(J)+BFNPP*GZETA(IR,J,K)                             STRS0850
  151 CONTINUE                                                          STRS0860
  503 CONTINUE                                                          STRS0870
  107 DO 101 J=1,NOGA                                                   STRS0880
      BINPW(J)=(CE1(IR,J)*(CEPS(J,1)**2/2.+CEPS(J,2)**2/2.)             STRS0890
     *-BINPP(J))*WET(IR,J)                                              STRS0900
      BIMPW(J)=(CE2(IR,J)*(CEPS(J,1)**2/2.+CEPS(J,2)**2/2.)             STRS0910
     *-BIMPP(J))*WET(IR,J)                                              STRS0920
      HWB(J,1)=(CE1(IR,J)*(CEPS(J,1)+CEPS(J,2)**2/2.+CEPS(J,1)**2/2.)   STRS0930
     *+CE2(IR,J)*CEPS(J,3)-BINPP(J))*CEPS(J,1)*WET(IR,J)                STRS0940
      HWB(J,2)=(CE1(IR,J)*(CEPS(J,1)+CEPS(J,2)**2/2.+CEPS(J,1)**2/2.)   STRS0950
     *+CE2(IR,J)*CEPS(J,3)-BINPP(J))*CEPS(J,2)*WET(IR,J)                STRS0960
  101  CONTINUE                                                         STRS0970
      DO 102 I=1,8                                                      STRS0980
      PN(I)=0.                                                          STRS0990
      PM(I)=0.                                                          STRS1000
      HNL(I)=0.0                                                        STRS1010
      DO 102 J=1,NOGA                                                   STRS1020
      PN(I)=PN(I)+BEP(IR,J,1,I)*BINPW(J)                                STRS1030
      PM(I)=PM(I)+BEP(IR,J,3,I)*BIMPW(J)                                STRS1040
  102 HNL(I)=HNL(I)+BEP(IR,J,2,I)*HWB(J,2)+BEP(IR,J,1,I)*HWB(J,1)       STRS1050
  200 DO 105 I=1,8                                                      STRS1060
  105 ELFP(I)=PN(I)+PM(I)+HNL(I)                                        STRS1070
     IF( YK(IR).EQ.0.0) GO TO 502                                       STRS1080
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      CALL ROTAT(2,DUMMY,ELFP,IR)                                       STRS1090
  502 CALL ASSEF(IR,IK,ELFP,FLVA,ICP)                                   STRS1100
       RETURN                                                           STRS1110
      END                                                               STRS1120
```

```
      SUBROUTINE TSTEP(AMASS,STIFK,DELTAT)                              TSTP0010
C     TO FIND DELTAT IF IT IS NOT SPECIFIED                             TSTP0020
      IMPLICIT REAL*8(A-H,O-Z)                                          TSTP0030
      DIMENSION AMASS(1),STIFK(1),TRIAL(205),VMULT(205),VECTR(205)      TSTP0040
     COMMON /FG/ IK,IKK,ICP,LREF,NOGA,NFL,NI,ICOL(205),INUM(205)        TSTP0050
    *,NBCOND,NBC(7),NODEB(7),KROW(8),NDEX(8),NIRREG                     TSTP0060
     COMMON/MAT/YOUNG(3,6),DS(3,6),SNO(3,5,6),NSFL(3,6),P(3,6),NLAY     TSTP0070
      COMMON /TAPE/ MREAD,MWRITE,MPUNCH                                 TSTP0080
      ABS(Q)=DABS(Q)                                                    TSTP0090
      SQRT(Q)=DSQRT(Q)                                                  TSTP0100
      INT(Q)=IDINT(Q)                                                   TSTP0110
      DO 3 K=1,NI                                                       TSTP0120
  3   TRIAL(K)=1.0                                                      TSTP0130
      IF(NBCOND .EQ. 0) GO TO 90                                        TSTP0140
      DO 91 I=1,NBCOND                                                  TSTP0150
      JT4=NODEB(I)*4                                                    TSTP0160
      JT4M3=JT4-3                                                       TSTP0170
      JT4M2=JT4-2                                                       TSTP0180
      JT4M1=JT4-1                                                       TSTP0190
      TRIAL(JT4M3)=0.0                                                  TSTP0200
      IF(NBC(I).EQ.1 .OR. NBC(I).EQ.2) TRIAL(JT4M1)=0.0                 TSTP0210
      IF(NBC(I).EQ.2 .OR. NBC(I).EQ.3) TRIAL(JT4M2)=0.0                 TSTP0220
 91   CONTINUE                                                          TSTP0230
 90   MRANK=NI                                                          TSTP0240
      BONE=0.                                                           TSTP0250
      EPSLN=1.0E-07                                                     TSTP0260
  2   BOLD=1.0                                                          TSTP0270
      DO 14 KKK=1,4                                                     TSTP0280
      DO 12 LLL=1,50                                                    TSTP0290
      DO 4 I=1,MRANK                                                    TSTP0300
  4   VMULT(I)=0.0                                                      TSTP0310
      CALL OMULT(STIFK,TRIAL,ICOL,NI,VMULT,KROW,NDEX,NIRREG)            TSTP0320
      CALL SOLV(AMASS,VMULT,VECTR,ICOL,KROW,NDEX,NI,NIRREG)             TSTP0330
      BNEW=-1.                                                          TSTP0340
      DO 6 K=1,MRANK                                                    TSTP0350
      IF(BNEW- ABS(VECTR(K)))60,60,6                                    TSTP0360
```

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```
 60     BNEW= ABS(VECTR(K))                                                    TSTP0370
 6      CONTINUE                                                               TSTP0380
        DO 7 K=1,MRANK                                                         TSTP0390
        IF(BNEW- ABS(VECTR(K)))7,8,7                                           TSTP0400
 7      CONTINUE                                                               TSTP0410
 8      MROW=K                                                                 TSTP0420
        BNEW=VECTR(K)                                                          TSTP0430
        DO 9 K=1,MRANK                                                         TSTP0440
 9      TRIAL(K)=VECTR(K)/BNEW                                                 TSTP0450
        IF( ABS(BNEW/BOLD-1.0)-EPSLN)15,15,10                                  TSTP0460
C       ITERATICN                                                              TSTP0470
 10     BKTH=BOLD                                                              TSTP0480
        BOLD=BNEW                                                              TSTP0490
 12     CONTINUE                                                               TSTP0500
        EPSLN=EPSLN*10.                                                        TSTP0510
 14     CONTINUE                                                               TSTP0520
C       NOT CONVERGING AFTER LL*KK ITERATIONS                                  TSTP0530
        EPSLN=1.0                                                              TSTP0540
        BONE=BNEW                                                              TSTP0550
        GO TO 32                                                               TSTP0560
C       EIGEN VALUE FCUND                                                      TSTP0570
 15     BONE=BNEW                                                              TSTP0580
 32     CONTINUE                                                               TSTP0590
        FREQ= SQRT(BONE)                                                       TSTP0600
        FACTCL=1.                                                              TSTP0610
       DELTAN=FACTCL*2./FREQ                                                   TSTP0620
        MP=0                                                                   TSTP0630
   20  DELTAN=DELTAN*10.                                                       TSTP0640
        MP=MP+1                                                                TSTP0650
       IF(DELTAN.LT.10.)  GO TO 20                                             TSTP0660
       DELTAN= INT(DEITAN) *10.**(-MP)                                         TSTP0670
        WRITE(MWRITE,25)FREQ                                                   TSTP0680
 25     FORMAT(/,'    HIGHEST NATURAL FREQUENCY (RAD/SEC) =',E17.8)            TSTP0690
       WRITE(MWRITE,500) DELTAN                                                TSTP0700
  500  FORMAT('ODELTAT SHOULD BE EQUAL TO OR LESS THAN', D15.6)                TSTP0710
       IF(DELTAT.EQ.0.0)  DELTAT =DELTAN                                       TSTP0720
```

```
      RETURN                                                      TSTP0730
      END                                                         TSTP0740
```


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6.2 Additional Subroutines Needed for JET 5A

These five (5) subroutines consist of:

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and are listed in the following:

```
C     (C)  COPYRIGHT 1978  MASSACHUSETTS INSTITUTE OF TECHNOLOGY
C       JET 5A MAIN PROGRAM FOR VARIABLE THICKNESS ARBITRARILY CURVED
C       MULTILAYER RING
C       JET 5A HOUBOLT OPERATOR
        IMPLICIT REAL*8(A-H,O-Z)
       DIMENSION ASFL(20,3, 8,3),GZETA(20,3, 8),SNS(20,3, 8,3),
     @ SNP(20,3, 8,3),AEP(20,3,8),DEP(20,2,3,8)
       DIMENSION STIFK(1400),SPRIN(1400),AMASS(1400),QDD(204),REACM(1400)
     @,REACK(1400), REAC(21), REAFM(205),REAFK(205)
       DIMENSION EPL2(3),EPL1(3), DISM3(205)
        DIMENSION           TXG(6),TWG(6),ES(3,6,6),FMECH(205)
        DIMENSION DDELD(205),DISUM(205),DIS(205),DISM1(205),DISM2(205),
     *FLR(205),FLN(205),FLVM(205)
     *,BMASS(1400),RH(3),HZ(3),HREF(50,3,3)
       DIMENSION BEPS(3,3),EPI(3),EPO(3)
       DIMENSION HDIF(3)
        DIMENSION HNIN(51),RMASS(51),UDOT(3),WDOT(3),ADOT(3)
       DIMENSION EFLN(6)
       DIMENSION DENS(3,6),B(6),EPS(3,5,6),SIG(3,5,6)
       DIMENSION NSBS(50),NSEL(50),AEPS(3)
       DIMENSION DISM(8) ,DELM(8), DUMMY(8,8)
       DIMENSION BIGA(6),BTIMA(6),IBIGA(6),ISTAA(6) ,ISURA(6)
       DIMENSION BI(6),BTIM(6),IBI(6),ISUR(6) , ITHR(51)
       COMMON/SC/ BIG(6),BTIME(6),IBIG(6),ISURF(6),ISTA(6)
       COMMON/MAT/YOUNG(3,6),DS(3,6),SNO(3,5,6),NSFL(3,6),P(3,6),NLAY
       COMMON/ADSP/ AZET(50),ASP(50),YSP(50),ZSP(50),LKK(50,11)
       COMMON/VQ/ FLVA(205),DISP(205),DELD(205),BINP(50,3),BIMP(50,3)
       COMMON /FG/ IK,IKK,ICP,LREF,NOGA,NFL,NI,ICOL(205),INUM(205)
     *,NBCOND,NBC(7),NODEB(7),KROW(8),NDEX(8),NIRREG
       COMMON /EP/ EPSI(50),EPSO(50)
        COMMON /TAPE/ MREAD,MWRITE,MPUNCH
        COMMON/FC/ Y(51),Z(51),ANG(51),H(51,3)
        COMMON/BA/ BEP(50,3,3,8),AL(50),AXG(3),AWG(3),WET(50,3),
     *CE1(50,3),CE2(50,3),CE3(50,3),CM1(50,3),CM2(50,3),CM3(50,3)
        COMMON /FORCE/ T1,AMP1FV,AMP1FW,T2,AMP2FV,AMP2FW,SLOPEV,SLOPEW,
     *AMPFV,AMPFW,ETA(4),RTOV(4),RTOW(4),RTO2V(4),RTO2W(4),RTO3V(4),
```


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```
     *RTO3W(4),FM1(4,8,2),FM2(2,4,8,2),FM3A(2,4,8,2),FM3B(2,4,8,2),     MAIN0370
     *NOFT1,NOFT2,NOFT3,JELEM(4),NSTF2(4),NELF2(4),NSTF3(4),NELF3(4)    MAIN0380
       COMMON /ELFU/ FQREF(205),REX(4),NQR,NORP,NORU                    MAIN0390
     *,NREL(4),NRST(4),NREU(4)                                          MAIN0400
      COMMON /ML/ MNEL(6),MATT(6)                                       MAIN0410
       COMMON /FRAG/ FH(3),FMASS(3),FMOI(3),UNK(3),CR(3),FCGU(3),FCGW(3)MAIN0420
     *,ALFA(3),DFCGU(3),DFCGW(3),DALFA(3),TREL,FKT(3),DELTAT,NF,MIMP    MAIN0430
      COMMON/BOUN/YK(51),NBCONB,NBCB(7),NODBB(7),MK(51),ROT(5,2)        MAIN0440
     *,XDIST(6),DROT(50),NODP(6)                                        MAIN0450
      COMMON /TIME/ IT                                                  MAIN0460
      COMMON/DIS/ ANGDI(50),NEDI(50),NDIS                               MAIN0470
      COMMON /BR/ NVEC(51,2), LMT(51)                                   MAIN0480
      COMMON /TAM/ MKE(51)                                              MAIN0490
      COMMON /THI/ HTH(5)                                               MAIN0500
       SIN(Q)=DSIN(Q)                                                   MAIN0510
       COS(Q)=DCOS(Q)                                                   MAIN0520
       ATAN(Q)=DATAN(Q)                                                 MAIN0530
       SQRT(Q)=DSQRT(Q)                                                 MAIN0540
       MREAD=5                                                          MAIN0550
       MWRITE=6                                                         MAIN0560
       MPUNCH=7                                                         MAIN0570
      NV1= 20                                                           MAIN0580
      NV2= 8                                                            MAIN0590
      NV3=3                                                             MAIN0600
    1 FORMAT(10I5)                                                      MAIN0610
2      FORMAT(3D15.6)                                                   MAIN0620
    3 FORMAT(3D25.16)                                                   MAIN0630
4      FORMAT(3D15.6/(4D15.6))                                          MAIN0640
5      FORMAT(5D15.6)                                                   MAIN0650
301    FORMAT(I5,2D15.6)                                                MAIN0660
303   FORMAT(5D15.6)                                                    MAIN0670
      IRRUN = 1                                                         MAIN0680
5555 WRITE(MWRITE,5556) IRRUN                                           MAIN0690
5556 FORMAT('1THIS IS RUN NUMBER',I3,'  FOR THIS JET 5A SUBMITTAL')     MAIN0700
       READ(MREAD,1) IK,ICP,NLAY,LREF,NOGA,NFL,MM,M1,M2,ICON            MAIN0710
      READ(MREAD,1) (NSFL(M,1),M=1,NLAY)                                MAIN0720
```

```
      DO 201 M=1,NLAY
      NSFLM= NSFL(M,1)
  201 READ(MREAD,4) DENS(M,1),DS(M,1),P(M,1),(EPS(M,L,1),SIG(M,L,1)
     *,L=1,NSFLM)
      READ(MREAD,2) B(1),DELTAT
      MNEL(1) = IK
       IKP1=IK+1
       IKK=IKP1
       IF(ICP.GT.0) IKK=IK
      NS= IKK
      MPU=1
C   IF A CONTINUATION DECK IS DESIRED, REMOVE THE FOLLOWING CARD: MPU=0
      MPU=0
      PIE= 3.141592653589793D+00
      NPZ1 = M1
      DO 7100 I=1,IKK
      DO 7100 J= 1,3
 7100 H(I,J) = 0.0
C   GEOMETRY GENERATION PERFORMED HERE
      READ(MREAD,2) (Y(I),Z(I),ANG(I),I=1,IKK)
      READ(MREAD,5)  ((H(I,M),M=1,NLAY),I=1,IKK)
      DO 111 I=1,IKK
  111 ANG(I)=ANG(I)*PIE/180.0
       IF(ICP.LE.0) GO TO 202
       Y(IKP1)=Y(1)
       Z(IKP1)=Z(1)
       ANG(IKP1)=ANG(1)
       DO 203 M=1,NLAY
 203   H(IKP1,M)=H(1,M)
 202   CONTINUE
      READ(MREAD,5300) NDIS
      NDI = NDIS
      IF(NDIS.EQ.0) GO TO 8100
      READ(MREAD,8101) (NEDI(I),ANGDI(I),I=1,NDIS)
 8101 FORMAT (4(I5,D15.6))
      DO 8102 I=1,NDIS
```


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```
8102 ANGDI(I) = (ANGDI(I)*PIE)/180.0                                         MAIN1090
8100 CONTINUE                                                                MAIN1100
     READ(MREAD,5300) NBR                                                    MAIN1110
5300 FORMAT(2I5)                                                             MAIN1120
     MNSFL= NSFL(1,1)                                                        MAIN1130
     DO 5666 I=1,NLAY                                                        MAIN1140
     IF(MNSFL.LT.NSFL(I,1)) MNSFL=NSFL(I,1)                                  MAIN1150
5666 CONTINUE                                                                MAIN1160
     DO 5305 I= 1,IK                                                         MAIN1170
     MKE(I) = 1                                                              MAIN1180
     LMT(I) = 0                                                              MAIN1190
     YK(I) = 0.0                                                             MAIN1200
     MK(I)= I                                                                MAIN1210
     NVEC(I,2) = I+1                                                         MAIN1220
5305 NVEC(I,1) = I                                                           MAIN1230
     IF (ICP.GT.0)     NVEC(IK,2) = 1                                        MAIN1240
     IF(ICP.LE.0) MK(IK+1) = IK+1                                            MAIN1250
     IF(NBR.NE.0) GOTO 1112                                                  MAIN1260
     WRITE(MWRITE,1113)                                                      MAIN1270
1113 FORMAT(//,' THERE ARE NO BRANCHES CONNECTED TO THE MAIN STRUCTURE MAIN1280
    @,THEREFORE',/,' THE NUMBERING SYSTEM FOR NODES AND ELEMENTS REMAINMAIN1290
    @S UNCHANGED')                                                           MAIN1300
1112 CONTINUE                                                                MAIN1310
     IF (NBR.EQ.0) GO TO 5310                                                MAIN1320
         CALL BRAN(NBR,DENS,EPS,SIG,B)                                       MAIN1330
     DO 8888 I=1,NBR                                                         MAIN1340
     IF(MNSFL.LT.NSFL(1,I+1)) MNSFL= NSFL(1,I+1)                             MAIN1350
8888 CONTINUE                                                                MAIN1360
5310 CONTINUE                                                                MAIN1370
     LGSP= 0                                                                 MAIN1380
     LSPP=0                                                                  MAIN1390
     READ(MREAD,8200) NOP,NASP,NTERF                                         MAIN1400
8200 FORMAT(3I5)                                                             MAIN1410
     DO 8215 I=1,IK                                                          MAIN1420
     DO 8215 J=1,2                                                           MAIN1430
8215 LKK(I,J) = 0                                                            MAIN1440
```

```
      IF(NOP.EQ.0) GO TO 8220
      IF (NOP.NE. 2)  LGSP=1
      IF(NOP.NE.1) LSPP=1
      IF(LSPP.NE.1) GO TO 8220
      READ (MREAD,8210) (NSBS(I),NSEL(I),AZET(I),I=1,NASP)
 8210 FORMAT(2I5,D15.6)
      WRITE(MWRITE,156)
  156 FORMAT('OADDITIONAL STRAIN POINT',5X,'ELEMENT',5X,'S  COORDINATE')
      DO 8216 J= 1,NASP
      IF(NSBS(J).NE.1) GO TO 8217
      M= NSEL(J) +1
      IF(ICP.GT.0.AND.NSEL(J).EQ.IK) MK(M) = IK+1
      N= MK(M) -1
      LKK(N,1) = 1 + LKK(N,1)
      NO = LKK(N,1) + 1
      LKK(N,NO) = J
      GOTO 1400
 8217 NNNN = NSBS(J)-1
      IF(NODP(NNNN).EQ.1) GOTO 8218
      NNNN= NODP(NNNN)
      N= MK(NNNN)+ NSEL(J)- 1
      GO TO 8219
 8218 N= NSEL(J)
 8219 LKK(N,1) = 1 + LKK(N,1)
      NO = LKK(N,1) +1
      LKK(N,NO) = J
 1400 WRITE(MWRITE,145) J,N,AZET(J)
  145 FORMAT(' ',9X,I5,13X,I5,7X,D15.6)
 8216 CONTINUE
 8220 CONTINUE
      IF(NDIS.EQ.0) GO TO 8140
      IF (NBR.EQ.0) GOTO  8145
      IF(NDI.EQ.0) GOTO 8145
      DO 8146 J= 1,NDI
      M= NEDI(J) +1
      N = MK(M) -1
```


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```
      NEDI(J) = N
 8146 CONTINUE
 8145 WRITE(MWRITE,8111)
       WRITE(MWRITE,8120) (NEDI(I),I=1,NDIS)
 8111 FORMAT('0EACH OF THE FOLLOWING ELEMENTS HAS A SLOPE DISCONTINUITY
     @AT ITS FIRST NODE')
 8120 FORMAT(' ', 25I5)
      WRITE(MWRITE,8112) (ANGDI(L),L=1,NDIS)
 8112 FORMAT('0THE GLOBAL SLOPE (RAD.) AT EACH DISCONTINUITY EQUALS:',/,
     @ (8D15.6))
      DO 8130 I= 1,NDIS
      M=NEDI(I)
      YK(M) = 2.0 + YK(M)
      L1= NVEC(M,1)
      DROT(M) = ANGDI(I) - ANG(L1)
 8130 CONTINUE
 8140 CONTINUE
       READ(MREAD,3) (AXG(K),K=1,NOGA)
       READ(MREAD,3) (AWG(K),K=1,NOGA)
       READ(MREAD,3) (TXG(K),K=1,NFL)
       READ(MREAD,3) (TWG(K),K=1,NFL)
C    FOR MEMBRANE SET TXG=0.0 AND TWG=2.0 FOR ONE DEPTHWISE STATION
       READ(MREAD,1) NBCOND, (NBC(I),NODEB(I),I=1,NBCOND)
      IF (NBR.EQ.0) GO TO 748
      NIT = NBCOND+ 1
      NIT1 = NIT -1
      NBCOND= NBCOND+NBCONB
      IF (NBCONB.EQ.0) GO TO 751
      DO 750 LOP= 1,NBCONB
      NBC(NIT1 + LOP) = NBCB(LOP)
  750 NODEB(NIT1 + LOP) = NODBB(LOP)
  751 IF (NIT1.EQ.0) GO TO 748
      DO 753 LOP = 1,NIT1
      NTI = NODEB(LOP)
  753 NODEB(LOP) = MK(NTI)
  748 CONTINUE
```

```
       READ (MREAD,1)  NQR,NORP,NORU
       NI=IKK*4
           CALL IDENT(NQR,B,DENS,EPS,SIG,NBR)
      WRITE(MWRITE,402)
  402 FORMAT(///,' GAUSSIAN STATIONS AND WEIGHTS:')
      WRITE(MWRITE,400)  (L,AXG(L),L, AWG(L),L=1,NOGA)
      WRITE(MWRITE,401)  (L,TXG(L),L,TWG(L),L=1,NFL)
  400 FORMAT(' ',12X,'AXG',I3,2X,'=',F20.15,8X,'AWG',I3,2X,'=',F20.15)
  401 FORMAT(' ',12X,'TXG',I3,2X,'=',F20.15,8X,'TWG',I3,2X,'=',F20.15)
      NBR1 = NBR+1
      DO 651 K=1,NBR1
      NLAP= NLAY
      IF(K.GT. 1)   NLAP=1
      DO 76  M=1,NLAP
      NSFLM=NSFL(M,K)
      ES(M,1,K) = SIG(M,1,K) /EPS(M,1,K)
       IF(NSFLM-1)  77,77,78
 78    DO 79 L=2,NSFLM
   79 ES(M,L,K)=(SIG(M,L,K)-SIG(M,L-1,K))/(EPS(M,L,K)-EPS(M,L-1,K))
   77 ES(M,NSFLM+1,K)  = 0.0
       DO 80 L=1,NSFLM
   80 SNO(M,L,K)=  ES(M,1,K) *EPS(M,L,K)
      YOUNG(M,K)=  ES(M,1,K)
   76 CONTINUE
  651 CONTINUE
      IC =  0
       DO 70 IR=1,IK
      IF(YK(IR).EQ.1.0.OR.YK(IR).EQ.3.0)  IC=IC+1
      L1= NVEC(IR,1)
      L2  = NVEC(IR,2)
      NLAP= NLAY
      IF(MKE(IR).GT.1)  NLAP=1
       DO 70  J=1,NOGA
      DO 71  M=1,NLAP
      IF(YK(IR).NE.1.0.AND.YK(IR).NE.3.0) GOTO 600
      IF  (ROT(IC,1).EQ.0.0)  GO TO 610
```


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```
      RH(M)= HTH(IC)*  (1.0-AXG(J))+H(L2,M)*AXG(J)
      GO TO 71
  610 RH(M)= H(L1,M)*  (1.0-AXG(J))+  HTH(IC)*AXG(J)
      GO TO 71
  600 RH(M)  = H(L1,M)*(1.0-AXG(J))+H(L2,M)*AXG(J)
   71 CONTINUE
       HZ(1)=RH(1)/2.
      IF(NLAP.EQ.1)  GO TO 72
       DO 73 M=2,NLAY
   73  HZ(M)=HZ(M-1)+(RH(M)+RH(M-1))/2.
   72  CONTINUE
       CM1(IR,J)=0.0
       CM2(IR,J)=0.0
       CM3(IR,J)=0.0
       CE1(IR,J)=0.0
       CE2(IR,J)=0.0
       CE3(IR,J)=0.0
      I= MKE(IP)
      DO 74  M=1,NLAP
       HREF(IR,J,M)=HZ(M)-HZ(LREF)
      CM1(IR,J)=CM1(IR,J)+DENS(M,I)*B(I)*RH(M)
      CM2(IR,J)=CM2(IR,J)-DENS(M,I)*B(I)*RH(M)*HREF(IR,J,M)
      CM3(IR,J)  =CM3(IR,J)+DENS(M,I)*B(I)*(RH(M)**3/12.
     *+HREF(IR,J,M)**2*RH(M))
C    FOR MEMBRANE SET CE2 AND CE3 = 0.0
      CE1(IR,J)=CE1(IR,J)+YOUNG(M,I)*B(I)*RH(M)
      CE2(IR,J)  = CE2(IR,J)+YOUNG(M,I)*B(I)*RH(M)*HREF(IR,J,M)
      CE3(IR,J)  = CE3(IR,J)+YOUNG(M,I)*B(I)*(RH(M)**3/12.0
     *+HREF(IR,J,M)**2*RH(M))
      NSFLM=NSFL(M,I)
       DO 75 N=1,NFL
       K=N+(M-1)*NFL
      GFL=RH(M)*TWG(N)*B(I)/2.0
       GZETA(IR,J,K)=RH(M)*TXG(N)/2.+HREF(IR,J,M)
       DO 75 L=1,NSFLM
      ASFL(IR,J,K,L)= GFL*(ES(M,L,I)-ES(M,L+1,I))/ES(M,1,I)
```

```
75    CONTINUE
74    CONTINUE
70    CONTINUE
     IF(NBR.NE.0) GOTO 218
      DO 15 I=1,8
15    ICOL(I)=1
      IKM1=IK-1
      IF(ICP.GT.0) GO TO 17
      DO 16 I=3,IKP1
      IK4=I*4
      IK3=IK4-1
      IK2=IK4-2
      IK1=IK4-3
      JJ=(I-1)*4-3
      ICOL(IK1)=JJ
      ICOL(IK2)=JJ
      ICOL(IK3)=JJ
      ICOL(IK4)=JJ
16    CONTINUE
      GO TO 19
17    DO 18 I=3,IKM1
      IK4=I*4
      IK3=IK4-1
      IK2=IK4-2
      IK1=IK4-3
      JJ=(I-1)*4-3
      ICOL(IK1)=JJ
      ICOL(IK2)=JJ
      ICOL(IK3)=JJ
      ICOL(IK4)=JJ
18    CONTINUE
      ICOL(IK*4)=1
      ICOL(IK*4-1)=1
      ICOL(IK*4-2)=1
      ICOL(IK*4-3)=1
19    CONTINUE
```


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```
 218 INUM(1)= 1                                                          MAIN3250
      DO 99 I=2,NI                                                       MAIN3260
 99   INUM(I) =I-ICOL(I-1)+INUM(I-1)                                     MAIN3270
      DO 990 I=1,NI                                                      MAIN3280
 990  INUM(I) =INUM(I) -ICOL(I)                                          MAIN3290
      NIRREG=0                                                           MAIN3300
      INDEX=0                                                            MAIN3310
      ISET=1                                                             MAIN3320
      DO 116 I=1,NI                                                      MAIN3330
      L=ICOL(I)                                                          MAIN3340
      IF (ICOL(I)-ISET)117,116,119                                       MAIN3350
 119  ISET=ICOL(I)                                                       MAIN3360
      GO TO 116                                                          MAIN3370
 117  NIRREG=NIRREG+1                                                    MAIN3380
      IF(NIRREG-NI/2)711,711,90                                          MAIN3390
 711  KROW(NIRREG)=I                                                     MAIN3400
      NDEX(NIRREG)=INDEX                                                 MAIN3410
 116  INDEX=INDEX+I-L                                                    MAIN3420
 90   ISIZE=NI+INUM(NI)                                                  MAIN3430
      WRITE(MWRITE,91) ISIZE                                             MAIN3440
 91   FORMAT(/,'   SIZE OF ASSEMBLED MASS OR STIFFNESS MATRIX=',I5)      MAIN3450
     IF(ISIZE.LE.2060) GOTO 6012                                         MAIN3460
     WRITE(MWRITE,6011)                                                  MAIN3470
 6011 FORMAT('OTHE SIZE OF THE STIFFNESS MATRIX HAS EXCEEDED 2060.  THISMAIN3480
    @ RUN HAS BEEN TERMINATED.  CHANGE DIMENSION OF STIFK IN',/,' MAINMAIN3490
    @,ELMPP,AND TSTEP.  ALSO CHANGE DIMENSIONS FOR AMASS,BMASS,AND SPRIMAIN3500
    @N')                                                                 MAIN3510
     GOTO 150                                                            MAIN3520
 6012 CONTINUE                                                           MAIN3530
     ELMPB=0.0                                                           MAIN3540
         CALL   ELMPP(AMASS,STIFK,ISIZE,AEP,DEP,NV1,REACK,REACH,ELMPB)MAIN3550
      DO 23 L=1,ISIZE                                                    MAIN3560
      BMASS(L)=AMASS(L)                                                  MAIN3570
 23   SPRIN(L)=0.0                                                       MAIN3580
     LLL=(IK-1)*26 +36                                                   MAIN3590
     WRITE(MWRITE,9030)                                                  MAIN3600
```

```
      WRITE(MWRITE,9035)  (BMASS(I),I=1,LLL)
      WRITE(MWRITE,9040)
      WRITE(MWRITE,9035)    (STIFK(I),I=1,LLL)
 9030 FORMAT('OBMASS  =')
 9035 FORMAT(' ', 8D16.8)
 9040 FORMAT('OSTIFK  =')
       CALL FAC(AMASS,ICOL,KROW,NDEX,IDET,MWRITE,NI,NIRREG,INUM)
       CALL TSTEP(AMASS,STIFK,DELTAT)
       IF (NQR .EQ. 0) GO TO 22
       CALL QREM(AL,AXG,AWG,SPRIN)
      DO 8612 I=1,ISIZE
 8612 REACK(I) = REACK(I)  + SPRIN(I)
      IF (NBCOND.EQ.0) GOTO 93
       DO 92 I=1,NBCOND
       JT4=NODEB(I)*4
       JT4M3=JT4-3
       JT4M2=JT4-2
       JT4M1=JT4-1
       CALL ERC(JT4M3,SPRIN,NI,ICOL,INUM)
       IF(NBC(I).EQ.1.OR.NBC(I).EQ.2) CALL ERC(JT4M1,SPRIN,NI,ICOL,INUM)
       IF(NBC(I).EQ.2.OR.NBC(I).EQ.3) CALL ERC(JT4M2,SPRIN,NI,ICOL,INUM)
   92 CONTINUE
   93 CONTINUE
  22  CONTINUE
      DO 8951 J=1,NOGA
 8951 EPL2(J)= 0.0
      EPAS2= 0.0
      BIGL= 0.0
      BIGAL=0.0
      M= NBR+1
      DO 10005 J= 1,M
      BIG(J) = 0.0
      BIGA(J) = 0.0
      BI(J) = 0.0
      IBIGA(J) = 0
      IBIG(J) = 0
```


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```
      IBI(J) = 0
      ISTA(J) = 0
      ISTAA(J) = 0
      BTIME(J) = 0.0
      BTIMA(J) = 0.0
      BTIM(J) = 0.0
10005 CONTINUE
       DTSQ=DELTAT**2
       C2=1./(2.*DELTAT**2)
       MCRIT=0
       IT=0
       TIME=0.0
             CALL IMPULS(NV,DELTAT,AL,SNS,SNP,NV1,NV2,NV3)
       READ(MREAD,5) TBEGIN,TFINAL,AMP1FV,AMP1FW
       IF(TFINAL .EQ. 0.0) WRITE(MWRITE,48)
 48    FORMAT('0   THERE IS NO TIME DEPENDENT FORCE DISTRIBUTION DURING
     * THIS RUN ')
       IF(TFINAL .EQ. 0.0) GO TO 49
       CALL LOADEQ(AL,AXG,AWG,TBEGIN,TFINAL)
 49    APDEN=0.0
       CINETO=0.0
       NREADF=0
       T1=TBEGIN
       NLOAD=2
       DO 34 I=1,NI
 34    FMECH(I)=0.0
       IF(TBEGIN.GT.0.0 .OR. TFINAL.EQ.0.0) GO TO 30
       NLOAD=1
             CALL LOADFT(TIME,NREADF,FMECH,AL)
       DO 25 L=1,ISIZE
 25    AMASS(L)=BMASS(L)
       CALL FAC(AMASS,ICOL,KROW,NDEX,IDET,MWRITE,NI,NIRREG,INUM)
       CALL SOLV(AMASS,FMECH,DDELD,ICOL,KROW,NDEX,NI,NIRREG)
       GO TO 31
 30    DO 32 I=1,NI
 32    DDELD(I)=0.0
```

```
31     DO 33 I=1,NI                                                  MAIN4330
33     DISUM(I)=2.*DTSQ*DDELD(I)+6.*DELD(I)+6.*DISP(I)               MAIN4340
       MLOAD=NLOAD                                                   MAIN4350
       DO 35 I=1,NI                                                  MAIN4360
       FLR(I)=FMECH(I)                                               MAIN4370
35     FLVM(I)=0.0                                                   MAIN4380
       CALL OMULT(BMASS,DISUM,ICOL,NI,FLVM,KROW,NDEX,NIRREG)         MAIN4390
       DO 37 L=1,ISIZE                                               MAIN4400
37     AMASS(L)=6.*BMASS(L)+DTSQ*(STIFK(L)+SPRIN(L))                 MAIN4410
       CALL FAC(AMASS,ICOL,KROW,NDEX,IDET,MWRITE,NI,NIRREG,INUM)     MAIN4420
       ITT=1                                                         MAIN4430
       TIME=ITT*DELTAT                                               MAIN4440
       NLOAD=2                                                       MAIN4450
      DO 69 I=1,NI                                                   MAIN4460
       FLVA(I)=0.0                                                   MAIN4470
   69 FMECH(I) =0.0                                                  MAIN4480
       IF(TIME.LT.TBEGIN .OR. TIME.GT.TFINAL) GO TO 38               MAIN4490
       NLOAD=1                                                       MAIN4500
             CALL LOADFT(TIME,NREADF,FMECH,AL)                       MAIN4510
 38    DO 39 I=1,NI                                                  MAIN4520
39     FLVM(I)=DTSQ*FMECH(I)+FLVM(I)                                 MAIN4530
       CALL SOLV(AMASS,FLVM,DIS,ICOL,KROW,NDEX,NI,NIRREG)            MAIN4540
       DO 61 I=1,NI                                                  MAIN4550
61     DELD(I)=DIS(I)-DISP(I)                                        MAIN4560
330    DO 376 I=1,NI                                                 MAIN4570
       DIS(I)=DISP(I)+DELD(I)                                        MAIN4580
       DISM1(I)=DTSQ*DDELD(I)-DIS(I)+2.*DISP(I)                      MAIN4590
376    CONTINUE                                                      MAIN4600
       DO 100 L=1,ISIZE                                              MAIN4610
100    AMASS(L)=2.*BMASS(L)+DTSQ*(STIFK(L)+SPRIN(L))                 MAIN4620
       CALL FAC(AMASS,ICOL,KROW,NDEX,IDET,MWRITE,NI,NIRREG,INUM)     MAIN4630
       IF(MLOAD .EQ. 2) GO TO 333                                    MAIN4640
       APD=0.0                                                       MAIN4650
       DO 46 I=1,NI                                                  MAIN4660
46      APD=APD+FLR(I)*DELD(I)                                       MAIN4670
       APDEN=APDEN+APD                                               MAIN4680
```


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333    CONTINUE                                                           MAIN4690
      DO 1020 I=1,IKK                                                     MAIN4700
      EPSI(I)= 0.0                                                        MAIN4710
 1020 EPSO(I) =0.0                                                        MAIN4720
      WRITE(MWRITE,8255) M2,NOP                                           MAIN4730
 8255 FORMAT('OTHE FOLLOWING IS THE TIME SOLUTION OF AN EXTERNALLY LOADEMAIN4740
     @D STRUCTURE.',/,' OUTPUT WILL BE PRINTED EVERY',I5,'  CYCLES USINGMAIN4750
     @OUTPUT OPTION',I3,'.',/,' REACTION FORCES APPLIED TO THE STRUCTUREMAIN4760
     @ WILL BE PRINTED AT EACH OUTPUT CYCLE',/,' FOR NODES AT WHICH BOUNMAIN4770
     @DARY CONDITIONS ARE SPECIFIED.  D.O.F. THAT ARE',/,' NOT RESTRAINEMAIN4780
     @D AT THAT NODE WILL HAVE A REACTION FORCE = 0.0.')                  MAIN4790
      TIME = 0.0                                                          MAIN4800
                  CALL PRINT(IT,TIME,HINN,HOUT,APDEN,SPRIN,BMASS,C2,      MAIN4810
     @NQR,CINETO,BEP,WET,NV,ES,ASFL,SNS,NV1,NV2,NV3)                      MAIN4820
 1280 FORMAT(I5,3D20.13)                                                  MAIN4830
 1281 FORMAT(4D20.13)                                                     MAIN4840
 1282 FORMAT(3I5,2D20.13)                                                 MAIN4850
 1283 FORMAT(2I5,2D20.13)                                                 MAIN4860
 1284 FORMAT(4D20.13)                                                     MAIN4870
      READ(MREAD,1) ICONT                                                 MAIN4880
      IF(ICONT.NE.0) GOTO 127                                             MAIN4890
      GOTO 120                                                            MAIN4900
  127 M=1+NBR                                                             MAIN4910
C   THESE ARE THE VALUES OF THE FOLLOWING VARIABLES TAKEN FROM A          MAIN4920
C   PREVIOUS RUN OF THIS PROBLEM.  THIS DATA WILL ALLOW A CONTINUATION    MAIN4930
C   RUN TO BE MADE.                                                       MAIN4940
      READ(MREAD,1280) ITT,TIME,T1,T2                                     MAIN4950
      READ(MREAD,1281) AMP1FV,AMP1FW,AMP2FV,AMP2FW                        MAIN4960
      READ(MREAD,1281)  SLOPEV,SLOPEW,APDEN,CINETO                        MAIN4970
       READ( MREAD,1282) (IBIGA(L),ISTAA(L),ISURA(L),BIGA(L),BTIMA(L),L MAIN4980
     @=1,M)                                                               MAIN4990
       READ( MREAD,1282)(IBIG(L),ISURF(L),ISTA(L),BIG(L),BTIME(L),L=1,M) MAIN5000
       READ( MREAD,1283)     (IBI(L),ISUR(L),BI(L),BTIM(L),L=1,M)        MAIN5010
       READ( MREAD,1284) (DISP(I),I=1,NI)                                 MAIN5020
       READ( MREAD,1284) (DELD(I),I=1,NI)                                 MAIN5030
       READ( MREAD,1284) (DIS (I),I=1,NI)                                 MAIN5040
```

```
      READ( MREAD,1284)  (DISM1(I),I=1,NI)
      READ( MREAD,1284)  (FMECH(I),I=1,NI)
      READ( MREAD,1284)  (FLVA(I)  ,I=1,NI)
      READ( MREAD,1284)  ((((SNS(IR,J,K,L),L=1,MNSFL),K=1,NV2),J=1,NOGA)
     @,IR=1,IK )
      READ( MREAD,1284)  ((((SNP(IR,J,K,L),L=1,MNSFL),K=1,NV2),J=1,NOGA)
     @,IR=1,IK )
     WRITE(MWRITE,8611)
 8611 FORMAT('0 THIS IS A CONTINUATION RUN.')
C    START OF TIME SOLUTION
 120  ITT=ITT+1
      TIME=ITT*DELTAT
 45   DO 121 I=1,NI
     DISM3(I) = DISM2(I)
      DISM2(I)=DISM1(I)
      DISM1(I)=DISP(I)
      DISP(I)=DIS(I)
      FLR(I)=FMECH(I)
      FLN(I)=FLVA(I)
      FLVA(I)=0.0
      FMECH(I)=0.0
      FLVM(I)=0.0
 121  DISUM(I)=5.*DISP(I)-4.*DISM1(I)+DISM2(I)
      IF(ICP.LE.0) GO TO 1277
      DO 128 K=1,4
      DISP(IK*4+K)=DISP(K)
 128  DELD(IK*4+K)=DELD(K)
 1277 CONTINUE
 345  CONTINUE
      MLOAD=NLOAD
           CALL STRESS(DELTAT,ASFL,GZETA,SNS,SNP,NV1,NV2,NV3)
      CALL OMULT(BMASS,DISUM,ICOL,NI,FLVM,KROW,NDEX,NIRREG)
      NLOAD=2
      IF(TIME.LT.TBEGIN .OR. TIME.GT.TFINAL) GO TO 122
      NLOAD=1
           CALL LOADPT(TIME,NREADF,FMECH,AL)
```


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122    DO 123 I=1,NI
123    FLVM(I)=(FMECH(I)-(2.*FLVA(I)-FLN(I)))*DTSQ+FLVM(I)
       IF(NBCOND .EQ. 0)  GO TO 124
       DO  125 I=1,NBCOND
       JT4=NODEB(I)*4
       FLVM(JT4-3)=0.0
       IF(NBC(I).EQ.1 .OR.  NBC(I).EQ.2)  FLVM(JT4-1)=0.0
       IF(NBC(I).EQ.2 .OR.  NBC(I).EQ.3)  FLVM(JT4-2)=0.0
125    CONTINUE
124    CALL SOLV(AMASS,FLVM,DIS,ICOL,KROW,NDEX,NI,NIRREG)
       DO 126 I=1,NI
126    DELD(I)=DIS(I)-DISP(I)
       IF(MLOAD .EQ. 2)  GO TO 41
       APD=0.0
       DO 42 I=1,NI
42      APD=APD+FLR(I)*DELD(I)
       APDEN=APDEN+APD
41     IT=ITT-1
       TIME=IT*DELTAT
      DO 6701 I=1,IKK
      ITHR(I) = 0
      EPSI(I) = 0.0
 6701 EPSO(I) = 0.0
      MIZ=0
      NPZ= IT-NPZ1
      IF(NPZ.NE.0)  GOTO 6700
      MIZ= 1
      NPZ1 = NPZ1+M2
      IF(LGSP.EQ.0)  GOTO 6700
      WRITE(MWRITE,11100)
      WRITE (MWRITE,6705) IT
 6705 FORMAT('0 CYCLE=' , I8)
      WRITE (MWRITE,6707)
 6707 FORMAT(' ELEMENT',9X,'SI',4X,'STA 1',4X,'SO',21X,'SI',4X,'STA 2',
     * 4X,'SO',21X,'SI',4X,'STA 3', 4X,'SO')
C    GAUSSIAN STATION STRAIN CALCULATION
```

```
6700 DO 7161 IR=1,IK
     K1= NVEC(IR,1)
     K2= NVEC(IR,2)
     LSS= MKE(IR)
     DO 8018 K=1,8
     INDEX= (K1-1)*4+K
     IF(K.GT.4) INDEX= (K2-1)*4+K-4
     DISM(K) = DISP(INDEX)
8018 CONTINUE
     IF(YK(IR).EQ.0.0) GOTO 901
          CALL ROTAT(1,DUMMY,DISM,IR)
 901 CONTINUE
     DO 604 I=1,NOGA
     DO 604 J=1,3
     BEPS (I,J)= 0.0
     DO 604 K=1,8
 604 BEPS(I,J)=BEPS(I,J) +BEP(IR,I,J,K)* DISM(K)
     NLAP= NLAY
     IF(MKE(IR).GT.1) NLAP =1
     H1= H(K1,1)
     H2 = H(K2,1)
     N=MKE(IR)-1
     IF(YK(IR).EQ.1.0.AND.ROT(N,1).EQ.1.0) H(K1,1)= HTH(N)
     IF(YK(IR).EQ.1.0.AND.ROT(N,1).EQ.0.0) H(K2,1)= HTH(N)
     DO 8908 LM= 1,NLAP
8908 HDIF(LM) = H(K2,LM) - H(K1,LM)
     DO 60 M=1,NOGA
     HINN=0.0
     HOUT = 0.0
     IF(NLAY.EQ.1) GOTO 8931
     IF(LREF-2) 8935,8936,8937
8935 HL1= (H(K1,1)+HDIF(1)*AXG(M))/2.0
     HL2= HL1+H(K1,2) +HDIF(2)*AXG(M)
     GOTO 8938
8936 HL1= -(H(K1,2) +HDIF(2)*AXG(M))/2.0
     HL2 = -HL1
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      IF (NLAP.EQ.2) HL2=0.0
      GOTO 8938
 8937 HL2=-(H(K1,3)+HDIF(3)*AXG(M))/2.0
      HL1= HL2-(H(K1,2)+HDIF(2)*AXG(M))
 8938 CONTINUE
      DO 8909 LM= 1,LREF
      DIVI= 1.0
      IF(LM.EQ.LREF) DIVI=2.0
      HINN= HINN+ (H(K1,LM) + HDIF(LM)*AXG(M)) / DIVI
 8909 CONTINUE
      DO 8911 LM= LREF,NLAP
      DIVI= 1.0
      IF(LM.EQ.LREF) DIVI=2.0
      HOUT= HOUT+ (H(K1,LM) + HDIF(LM)*   AXG(M )) / DIVI
 8911 CONTINUE
      GOTO 8932
 8931 HINN= (H(K1,1)+ HDIF(1)*AXG(M)) /2.0
      HOUT = HINN
      HL1= 0.0
      HL2= 0.0
 8932 CONTINUE
      FARE= BEPS(M,1)+BEPS(M,2)**2/2.0
     *+BEPS(M,1)**2/2.
      IF(NTERF.EQ.0) GOTO  8939
      IF(NLAP.EQ.1) GOTO 8939
C    FOR MEMBRANE SET HL1 AND HL2 =0.0
      EPL1(M) = FARE+HL1*BEPS(M,3)
      EPL2(M) = FARE+HL2*BEPS(M,3)
      IF(NLAP.EQ.2) EPL2(M)= 0.0
      IF(EPL1(M).LE.BIGL) GOTO 8940
      BIGL= EPL1(M)
      IBIGL= IR
      ISTAL= M
      ISURFL=1
      BTIMEL= TIME
 8940 IF(NLAY.EQ.2) GOTO 8939
```

```
      IF(EPL2(M).LE.BIGL) GOTO 8939
      BIGL= EPL2(M)
      IBIGL= IR
      ISTAL= M
      ISURFL=2
      BTIMEL= TIME
 8939 CONTINUE
C   FOR MEMBRANE SET HINN AND HOUT =0.0
      EPI(M)= FARE- HINN*BEPS(M,3)
      EPO(M) = FARE+HOUT*BEPS(M,3)
      IF(EPI(M).LE.BIG(LSS)) GO TO 591
      BIG(LSS) = EPI(M)
      IBIG(LSS)= IR
      ISTA(LSS) = M
      ISURF(LSS) = 1
      BTIME(LSS) = TIME
  591 IF(EPO(M).LE.BIG(LSS)) GO TO 1200
      BIG(LSS) = EPO(M)
      IBIG(LSS)= IR
      ISTA(LSS) = M
      ISURF(LSS) = 2
      BTIME(LSS) = TIME
 1200 CONTINUE
 60     CONTINUE
C   AVERAGE NODAL STRAIN CALCULATION
C   AT A  NODE WHERE A BRANCH ATTACHES TO THE MAIN STRUCTURE,
C     THE BRANCH'S NODAL STRAIN IS NOT AVERAGED IN
      DO 6604 I=1,2
      DO 6604 J=1,3
      BEPS( I,J) = 0.0
      DO 6604 K=1,8
 6604 BEPS(I,J) = BEPS(I,J)  +DEP(IR,I,J,K)* DISM(K)
      FAR1 =BEPS(1,1)+BEPS(1,2)**2/2.0 +BEPS(1,1)**2/2.0
      FAR2 =BEPS(2,1)+BEPS(2,2)**2/2.0 +BEPS(2,1)**2/2.0
      NKE = MKE(IR)
      NLAP = NLAY
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      IF (NKE.GT.1) NLAP=1
      IF(NLAP.EQ.1) GOTO 6631
      THI1= 0.0
      THO1 =0.0
      THI2= 0.0
      THO2= 0.0
      DO 6619 L=1,LREF
      DIVI= 1.0
      IF(L.EQ.LREF) DIVI=2.0
      THI1= THI1 + H(K1,L)/DIVI
 6619 THI2= THI2+ H(K2,L)/DIVI
      DO 6620 L= LREF,NLAP
      DIVI =1.0
      IF(L.EQ.LREF) DIVI= 2.0
      THO1= THO1+ H(K1,L)/DIVI
 6620 THO2= THO2+ H(K2,L)/DIVI
      GOTO 6622
 6631 THI1= H(K1,1)/2.0
      THI2= H(K2,1)/2.0
      THO1= THI1
      THO2= THI2
 6622 CONTINUE
      IF (NKE.EQ.1) GOTO 6605
      IF(MATT(NKE-1).EQ.K1) GOTO 6606
 6605 ADEN = 1.0
      IF(ITHR(K1).GT.0)  ADEN=2.0
      ITHR(K1) = 1
C    FOR MEMBRANE SET THI1,THO1,THI2,THO2=0.0
      EPSI(K1)=(EPSI(K1)  + FAR1- THI1*BEPS(1,3)/2.0)  /ADEN
      EPSO(K1) =(EPSO(K1) + FAR1+ THO1*BEPS(1,3)/2.0)  /ADEN
      IF(NKE.EQ.1) GOTO 6606
      IF (MATT(NKE-1).EQ.K2)  GOTO 6607
 6606 ADEN = 1.0
      IF (ITHR(K2).GT.0)  ADEN=2.0
      ITHR(K2) = 1
      EPSI(K2) =(EPSI(K2) + FAR2-  THI2*BEPS(2,3)/2.0) /ADEN
```

```
      EPSO(K2)=(EPSO(K2) + FAR2+ THO2 * BEPS(2,3)/2.0 ) /ADEN
 6607 CONTINUE
      H(K1,1) = H1
      H(K2,1) = H2
      IF (MIZ.NE.1) GO TO 7161
      IF(LGSP.EQ.0) GO TO 7161
 7940 WRITE(MWRITE,6710) IR,(EPI(L),EPO(L),L=1,3)
 6710 FORMAT(' ',I3,2X,3(3X,D15.8,3X,D15.8,3X))
      IF(NLAP.EQ.1) GOTO 7161
      IF(NTERF.EQ.0) GOTO 7161
      WRITE(MWRITE,6609) (EPL1(L),EPL2(L),L=1,3)
 6609 FORMAT(' ',5X,3(3X,D15.8,3X,D15.8,3X))
 7161  CONTINUE
C    FIND LARGEST AVERAGE NODAL STRAIN
      DO 7170 I= 1,IKK
      N= 0
      DO 7171 IR=1,IK
      IF(NVEC(IR,1).NE.I) GOTO 7172
      IF(MKE(IR).EQ.1) N= N+1
      IF(MKE(IR).GT.1)  N= N+3
      IF(MKE(IR).GT.1) NKE=MKE(IR)
 7172 CONTINUE
      IF(NVEC(IR,2).NE.I) GOTO 7171
      IF(MKE(IR).EQ.1) N=N+1
      IF(MKE(IR).GT.1)  N= N+3
      IF(MKE(IR).GT.1)  NKE= MKE(IR)
 7171 CONTINUE
      NK=1
      IF(N.EQ.3.OR.N.EQ.6) NK=NKE
      IF(EPSI(I).LE.BI(NK)) GOTO 7174
      BI(NK) = EPSI(I)
      IBI(NK) = I
      ISUR(NK) = 1
      BTIM(NK) = TIME
 7174 IF(EPSO(I).LE.BI(NK)) GOTO 7170
      BI(NK) = EPSO(I)
```

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      IBI(NK) = I
      ISUR(NK) = 2
      BTIM(NK) = TIME
 7170 CONTINUE
 7180 CONTINUE
      IF(LSPP.EQ.0) GOTO 8562
      IF(MIZ.NE.1) GOTO 8700
      WRITE(MWRITE,6705) IT
      WRITE(MWRITE,8707)
 8707 FORMAT(' STRAIN AT ADDITIONAL POINTS',10X,'SI',18X,'SO',23X,'EI',
     @18X,'EO')
 8700 DO 8761 IR= 1,IK
      IF(LKK(IR,1).EQ.0)  GOTO 8761
      NLAP= NLAY
      IF(MKE(IR).GT.1)  NLAP =1
      K1 = NVEC(IR,1)
      K2= NVEC(IR,2)
      DO 8019 K=1,8
      INDEX= (K1-1)*4+K
      IF(K.GT.4) INDEX= (K2-1)*4+K-4
      DISM(K) = DISP(INDEX)
 8019 CONTINUE
      IF(YK(IR).EQ.0.0) GOTO 902
           CALL ROTAT(1,DUMMY,DISM,IR)
  902 CONTINUE
      H1= H(K1,1)
      H2 = H(K2,1)
      L= MKE(IR)
      N=MKE(IR)-1
      IF(YK(IR).EQ.1.0.AND.ROT(N,1).EQ.1.0) H(K1,1)= HTH(N)
      IF(YK(IR).EQ.1.0.AND.ROT(N,1).EQ.0.0) H(K2,1)= HTH(N)
      NO= LKK(IR,1)
      DO 8763 I= 1,NO
      IS = LKK(IR,I+1)
      DO 8604 J=1,3
      AEPS(J) = 0.0
```

```
      DO 8604 K= 1,8
 8604 AEPS (J)=AEPS (J)  + AEP (IS, J, K) *DISM(K)
      DO 8918 LM= 1,NLAP
 8918 HDIF (LM)  = H(K2,LM)- H(K1,LM)
      HINN=0.0
      HOUT = 0.0
      IF(NLAP.EQ.1) GOTO 8941
      IF(LREF-2) 8735,8736,8737
 8735 HL1=  (H(K1,1)+HDIF(1) *AXG(M)) /2.0
      HL2= HL1+ H(K1,2) +HDIF(2)*AXG(M)
      GOTO 8738
 8736 HL1= -(H(K1,2) +HDIF(2) * AXG(M)) /2.0
      HL2=  -HL1
      IF(NLAP.EQ.2) HL2= 0.0
      GOTO 8738
 8737 HL2= - (H(K1,3)+HDIF(3) *AXG(M)) /2.0
      HL1= HL2-(H(K1,2) +HDIF (2)*AXG(M))
 8738 CONTINUE
      DO 8919 LM= 1,LREF
      DIVI= 1.0
      IF(LM.EQ.LREF) DIVI=2.0
      HINN= HINN+ (H(K1,LM) + HDIF (LM) *AZET(IS)) / DIVI
 8919 CONTINUE
      DO 8921 LM= LREF,NLAP
      DIVI= 1.0
      IF(LM.EQ.LREF) DIVI=2.0
      HOUT= HOUT+ (H(K1,LM)+ HDIF(LM)*  AZET(IS)) / DIVI
 8921 CONTINUE
      GOTO 8942
 8941 HINN= (H(K1,1) +HDIF(1)*AZET(IS))/ 2.0
      HOUT = HINN
      HL1= 0.0
      HL2= 0.0
 8942 CONTINUE
      FARE= AEPS(1)+AEPS(2)**2/2.0+AEPS(1)**2/2.0
      IF(NTERF.EQ.0) GOTO 8739
```

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```
      IF(NLAP.EQ.1) GOTO 8739
C    FOR MEMBRANE SET HL1 AND HL2 =0.0
      EPAS1= FARE+HL1* AEPS(3)
      EPAS2= FARE+HL2*AEPS(3)
      IF(NLAP.EQ.2)  EPAS2= 0.0
      IF(EPAS1.LE.BIGAL) GOTO 8740
      BIGAL= EPAS1
      IBIGAL= IR
      ISTAAL= IS
      BTIMAL= TIME
      ISURAL= 1
 8740 IF(NLAY.EQ.2) GOTO  8739
      IF(EPAS2.LE.BIGAL) GOTO 8739
      BIGAL= EPAS2
      IBIGAL= IR
      ISTAAL= IS
      BTIMAL= TIME
      ISURAL = 2
 8739 CONTINUE
C    FOR MEMBRANE SET HINN AND HOUT =0.0
      EPASI  = FARE- HINN*AEPS(3)
      EPASO  = FARE+ HOUT*AEPS(3)
C    FIND LARGEST ADDTIONAL POINT STRAIN
      IF(EPASI.LE.BIGA(L))   GO TO 8591
      BIGA(L)  = EPASI
      IBIGA(L)  = IR
      ISTAA(L)  = IS
      BTIMA(L)  = TIME
      ISURA(L)  = 1
 8591 IF(EPASO.LE.BIGA(L)) GO TO 8780
      BIGA(L)  = EPASO
      IBIGA(L)  = IR
      ISTAA(L)  = IS
      BTIMA(L)  = TIME
      ISURA(L)  = 2
 8780 IF(MIZ.NE.1)  GO TO 8763
```

```
      EI= DSQRT(1.0+2.0* EPASI) -1.0                                        MAIN8650
      EO= DSQRT(1.0+2.0* EPASO) -1.0                                        MAIN8660
      WRITE(MWRITE,8781) IS,EPASI,EPASO,EI,EO                               MAIN8670
 8781 FORMAT(' ',10X,I3,16X,D15.8,4X,D15.8,11X,D15.8,4X,D15.8)             MAIN8680
      IF(NLAP.EQ.1) GOTO 8763                                               MAIN8690
      IF (NTERF.EQ.0) GOTO 8763                                             MAIN8700
      WRITE(MWRITE,8609) EPAS1,EPAS2                                        MAIN8710
 8609 FORMAT(' ',29X,D15.8,4X,D15.8)                                        MAIN8720
 8763 CONTINUE                                                              MAIN8730
      H(K1,1) = H1                                                          MAIN8740
      H(K2,1) = H2                                                          MAIN8750
 8761 CONTINUE                                                              MAIN8760
 8562 CONTINUE                                                              MAIN8770
       IF(IT.EQ.1) CALL PRINT(IT,TIME,HINN,HOUT,APDEN,SPRIN,BMASS,C2,       MAIN8780
     *NQR,CINETO,BEP,WET,NV,ES,ASFL,SNS,NV1,NV2,NV3)                        MAIN8790
       IF(IT-M1) 131,140,150                                                MAIN8800
 140   M1=M1+M2                                                             MAIN8810
       CALL PRINT(IT,TIME,HINN,HOUT,APDEN,SPRIN,BMASS,C2,NQR,CINETO,        MAIN8820
     *BEP,WET,NV,ES,ASFL,SNS,NV1,NV2,NV3)                                   MAIN8830
      IF(NBCOND.EQ.0) GOTO 1260                                             MAIN8840
      DO 1276 I=1,NI                                                        MAIN8850
      QDD(I)= (2.0*DISP(I)-5.0*DISM1(I)+4.0*DISM2(I)-DISM3(I))/DTSQ         MAIN8860
      REAFM(I)= 0.0                                                         MAIN8870
      REAFK(I)= 0.0                                                         MAIN8880
 1276 CONTINUE                                                              MAIN8890
      CALL OMULT(REACM,QDD,ICOL,NI,REAFM,KROW,NDEX,NIRREG)                  MAIN8900
      CALL OMULT(REACK,DISP,ICOL,NI,REAFK,KROW,NDEX,NIRREG)                 MAIN8910
      DO  1261 I=1,21                                                       MAIN8920
 1261 REAC(I)= 0.0                                                          MAIN8930
      DO 1262 I=1,NBCOND                                                    MAIN8940
      J= NODEB(I)*4                                                         MAIN8950
      K= (I-1)*3                                                            MAIN8960
      REAC(K+1)= REAFM(J-3)+REAFK(J-3)-(FLR(J-3)-FLVA(J-3))                 MAIN8970
      IF(NBC(I).EQ.1.OR.NBC(I).EQ.2) REAC(K+3)=REAFM(J-1)+REAFK(J-1)-       MAIN8980
     @(FLR(J-1)-FLVA(J-1))                                                  MAIN8990
      IF(NBC(I).EQ.2.OR.NBC(I).EQ.3) REAC(K+2)=REAFM(J-2)+REAFK(J-2)-       MAIN9000
```


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     @(FLR(J-2)-FLVA(J-2))
 1262 CONTINUE
      WRITE(MWRITE,1256)
 1256 FORMAT('0',6X,'REACTIONS AT NODE',15X,'RV(LBS)',13X,'RW(LBS)',
     @11X,'RM(IN-LBS)')
      DO 1252 I=1,NBCOND
      J=  (I-1) *3
      WRITE(MWRITE,1253) NODEB(I), REAC(J+1),REAC(J+2),REAC(J+3)
 1253 FORMAT(' ',18X,I4,5X,3D20.6)
 1252 CONTINUE
 1260 CONTINUE
      M=NBR+1
      WRITE(MWRITE,66)
      WRITE(MWRITE,67)(L,BIG(L),IBIG(L),ISURF(L),ISTA(L),BTIME(L),L=1,M)
      IF(NTERF.EQ.0) GOTO 1272
      WRITE(MWRITE,1270) BIGL,IBIGL,ISURFL,ISTAL,BTIMEL
 1270 FORMAT(' INTERFACE',4X,D15.6,1X,I4,4X,I4,4X,I4,4X,D15.6)
 1272 CONTINUE
      IF(LSPP.NE.1) GO TO 8782
      WRITE(MWRITE,6030)
      WRITE(MWRITE,6035) (L,BIGA(L),IBIGA(L),ISTAA(L),BTIMA(L),ISURA(L),
     @L=1,M)
      IF(NTERF.EQ.0) GOTO 1273
      WRITE(MWRITE,1271)  BIGAL,IBIGAL,ISTAAL,BTIMAL,ISURAL
 1271 FORMAT(' INTERFACE',14X,D15.6,7X,I3,6X,I5,5X,D15.6,6X,I4)
 1273 CONTINUE
 8782 CONTINUE
      WRITE(MWRITE,7181)
      WRITE(MWRITE,7182)(L,BI(L),IBI(L),ISUR(L),BTIM(L),L=1,M)
 7181 FORMAT('OSUBSTRUCTURE',5X,'LARGEST  NODAL  STRAIN ',5X,'NODE',7X,
     @'SURF',11X,'TIME')
 7182 FORMAT(' ',4X,I3,16X,D15.6,7X,I3,6X,I5,5X,D15.6)
      WRITE(MWRITE,11100)
11100 FORMAT('0*********************************************************
     @****************************************************************
     @********',/)
```

```
 131  IF(IT-MM) 120,170,150
 170 CONTINUE
     WRITE(MWRITE,6002)
6002 FORMAT('OTHE LARGEST COMPUTED STRAINS FOR EACH SUBSTRUCTURE--
    @MAIN AND BRANCHES -- ARE PRINTED BELOW,  1= INNER  2= OUTER SURF')
     M= NBR+1
     WRITE(MWRITE,66)
     WRITE(MWRITE,67) (L,BIG(L),IBIG(L),ISURF(L),ISTA(L),BTIME(L),L=1,M)
  66 FORMAT('OSUBSTRUCTURE',8X,'MSTR',7X,'ELE',5X,'SURF',5X,'STA',
    @9X,'TIME')
  67 FORMAT(' ',3X,I4,6X,D15.6,1X,I4,4X,I4,4X,I4,4X,D15.6)
     IF (NTERF.EQ.0) GOTO 1274
     WRITE(MWRITE,1270) BIGL,IBIGL,ISURFL,ISTAL,BTIMEL
1274 CONTINUE
     IF(LSPP.NE.1) GOTO 149
     WRITE(MWRITE,6030)
     WRITE(MWRITE,6035) (L,BIGA(L),IBIGA(L),ISTAA(L),BTIMA(L),ISURA(L),
    @L=1,M)
6030 FORMAT('OSUBSTRUCTURE',5X,'LARGEST ADD. PT. STRAIN',5X,'ELEM',5X,
    @'ADD. PT.',9X,'TIME',10X,'SURFACE')
6035 FORMAT(' ',4X,I3,16X,D15.6,7X,I3,6X,I5,5X,D15.6,6X,I4)
     IF (NTERF.EQ.0) GOTO 1275
     WRITE(MWRITE,1271)  BIGAL,IBIGAL,ISTAAL,BTIMAL,ISURAL
1275 CONTINUE
 149 CONTINUE
     WRITE(MWRITE,7181)
     WRITE(MWRITE,7182) (L,BI(L),IBI(L),ISUR(L),BTIM(L),L=1,M)
 150 IF (MPU.EQ.0) GOTO 160
     M= NBR+1
     WRITE(MPUNCH,1280) ITT,TIME,T1,T2
     WRITE(MPUNCH,1281) AMP1FV,AMP1FW,AMP2FV,AMP2FW
     WRITE(MPUNCH,1281) SLOPEV,SLOPEW,APDEN,CINETO
     WRITE(MPUNCH,1282) (IBIGA(L),ISTAA(L),ISURA(L),BIGA(L),BTIMA(L),L
    @=1,M)
     WRITE(MPUNCH,1282) (IBIG(L),ISURF(L),ISTA(L),BIG(L),BTIME(L),L=1,M)
     WRITE(MPUNCH,1283)     (IBI(L),ISUR(L),BI(L),BTIM(L),L=1,M)
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      WRITE(MPUNCH,1284)  (DISP(I),I=1,NI)                              MAIN9730
      WRITE(MPUNCH,1284)  (DELD(I),I=1,NI)                              MAIN9740
      WRITE(MPUNCH,1284)  (DIS (I),I=1,NI)                              MAIN9750
      WRITE(MPUNCH,1284)  (DISM1(I),I=1,NI)                             MAIN9760
      WRITE(MPUNCH,1284)  (FMECH(I),I=1,NI)                             MAIN9770
      WRITE(MPUNCH,1284)  (FLVA(I)  ,I=1,NI)                            MAIN9780
      WRITE(MPUNCH,1284)  ((((SNS(IR,J,K,L),L=1,MNSFL),K=1,NV2),J=1,NOGA)MAIN9790
     @,IR=1,IK )                                                        MAIN9800
      WRITE(MPUNCH,1284)  ((((SNP(IR,J,K,L),L=1,MNSFL),K=1,NV2),J=1,NOGA)MAIN9810
     @,IR=1,IK )                                                        MAIN9820
      GOTO 162                                                          MAIN9830
  160 WRITE(MWRITE,161)                                                 MAIN9840
  161 FORMAT('OTHERE ARE NO CARDS PUNCHED FOR CONTINUATION')            MAIN9850
  162 IF(ICON.EQ.0)  GOTO 151                                           MAIN9860
      IRRUN = IRRUN +1                                                  MAIN9870
      GO TO 5555                                                        MAIN9880
  151 CALL EXIT                                                         MAIN9890
      END                                                               MAIN9900
```

```
      SUBROUTINE IMPULS(NV,DELTAT,AL,SNS,SNP,NV1,NV2,NV3)
       IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION SNS(NV1,3,NV2,NV3),SNP(NV1,3,NV2,NV3)
       DIMENSION AL(50)
      COMMON/MAT/YOUNG(3,6),DS(3,6),SNO(3,5,6),NSFL(3,6),P(3,6),NLAY
      COMMON /FG/ IK,IKK,ICP,LREF,NOGA,NFL,NI,ICOL(205),INUM(205)
     *,NBCOND,NBC(7),NODEB(7),KROW(8),NDEX(8),NIRREG
      COMMON/VQ/ FLVA(205),DISP(205),DELD(205),BINP(50,3),BIMP(50,3)
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      COMMON /TAM/ MKE(51)
       SIN(Q)=DSIN(Q)
       COS(Q)=DCOS(Q)
       DO 50 I=1,NI
       DELD(I)=0.0
50      DISP(I)=0.0
       DO 51 IR=1,IK
      NLAP= NLAY
      IF(MKE(IR).GT.1)  NLAP=1
      NO = MKE(IR)
       DO 51 J=1,NOGA
       BINP(IR,J)=0.0
       BIMP(IR,J)=0.0
      DO 51 M=1,NLAP
      NSFLM=NSFL(M,NO)
       DO 51 N=1,NFL
       K=N+(M-1)*NFL
       DO 51 L=1,NSFLM
       SNP(IR,J,K,I)=0.0
51     SNS(IR,J,K,L)=0.0
       READ(MREAD,1) NV,IOTA,IOTB,IOTC
1      FORMAT(4I5)
       WRITE(MWRITE,2) DELTAT
2       FORMAT(/,'    TIME STEP SIZE USED IN PROGRAM (SEC) =',E15.6)
       IF(NV .EQ. 0) WRITE(MWRITE,4)
       IF(NV .GT. 0) WRITE(MWRITE,6)
4      FORMAT(/,'    THERE IS NO INITIAL IMPULSE  ')
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6     FORMAT(/,'     IMPULSE LOADINGS HAVE BEEN SPECIFIED AS DESCRIBED BYIMPU0370
     * INPUT ')                                                          IMPU0380
      IF(NV .EQ. 0) GO TO 43                                            IMPU0390
      IF(IOTA .EQ.0) GO TO 10                                           IMPU0400
     WRITE(MWRITE,100) IOTA                                             IMPU0410
100  FORMAT('0',I4,'    LOCAL INITIAL NORMAL VELOCITY FIELDS ARE DESCRIBIMPU0420
    @ED BELOW:',//,' FIRST ELEM',5X,'TOTAL ELEMS',10X,'WRAD',15X,'WRAD1IMPU0430
    @',15X,'ANGV1',15X,'WRAD2',15X,'ANGV2')                             IMPU0440
      DO 20 IM=1,IOTA                                                   IMPU0450
      READ(MREAD,21) IE1,IE2,WRAD,WRAD1,ANGV1,WRAD2,ANGV2               IMPU0460
21    FORMAT(2I5/5E15.6)                                                IMPU0470
     WRITE(MWRITE,105) IE1,IE2,WRAD,WRAD1,ANGV1,WRAD2,ANGV2             IMPU0480
 105 FORMAT(' ',I6,13X,I3,9X,D13.6,8X,D13.6,7X,D13.6,7X,D13.6,7X,D13.6)IMPU0490
      IE2M1=IE2-1                                                       IMPU0500
      DO 22 II=1,IE2M1                                                  IMPU0510
      I=IE1+II                                                          IMPU0520
      IF(ICP.LE.0) GO TO 22                                             IMPU0530
      IF(I .GT. IK) I=I-IK                                              IMPU0540
22    DELD(I*4-2)=DELTAT*WRAD                                           IMPU0550
      DELD(IE1*4-2)=DELTAT*WRAD1                                        IMPU0560
      DELD(IE1*4-1)=DELTAT*ANGV1                                        IMPU0570
      IE2P1=IE1+IE2                                                     IMPU0580
      IF(ICP.LE. 0) GO TO 23                                            IMPU0590
      IF(IE2P1 .GT. IK) IE2P1=IE2P1-IK                                  IMPU0600
23    DELD(IE2P1*4-2)=DELTAT*WRAD2                                      IMPU0610
      DELD(IE2P1*4-1)=DELTAT*ANGV2                                      IMPU0620
20    CONTINUE                                                          IMPU0630
10    IF(IOTB .EQ. 0) GO TO 41                                          IMPU0640
     WRITE(MWRITE,110) IOTB                                             IMPU0650
 110 FORMAT('0',I4,'    NODAL VELOCITY IMPULSES ARE DESCRIBED BELOW:',  IMPU0660
    @//,' NODE',10X,'VRAD',20X,'WRAD',20X,'ANGV')                       IMPU0670
      DO 30 IM=1,IOTB                                                   IMPU0680
      READ(MREAD,31) NODEV,VRAD,WRAD,ANGV                               IMPU0690
31    FORMAT(I5,3E15.6)                                                 IMPU0700
     WRITE(MWRITE,115)  NODEV,VRAD,WRAD,ANGV                            IMPU0710
 115 FORMAT(' ',I3,6X,D13.6,11X,D13.6,11X,D13.6)                        IMPU0720
```

```
      DELD(NODEV*4-3)=DELTAT*VRAD                                       IMPU0730
      DELD(NODEV*4-2)=DELTAT*WRAD                                       IMPU0740
      DELD(NODEV*4-1)=DELTAT*ANGV                                       IMPU0750
30    CONTINUE                                                          IMPU0760
41    IF(IOTC .EQ. 0) GO TO 60                                          IMPU0770
     WRITE(MWRITE,120) IOTC                                             IMPU0780
120  FORMAT('0',I4,'  SINE SHAPED VELOCITY FIELDS ARE DESCRIBED BELOW:'IMPU0790
    @,//,' FIRST ELEM',5X,'TOTAL ELEMS',10X,'WRAD')                     IMPU0800
      DO 61 IM=1,IOTC                                                   IMPU0810
      READ(MREAD,62) IS1,IS2,WRAD                                       IMPU0820
62    FORMAT(2I5,E15.6)                                                 IMPU0830
     WRITE(MWRITE,125) IS1,IS2,WRAD                                     IMPU0840
 125 FORMAT(' ', I6,13X,I3,9X,D13.6)                                    IMPU0850
      TX=0.0                                                            IMPU0860
      DO 65 NN=1,IS2                                                    IMPU0870
      NE=(IS1-1)+NN                                                     IMPU0880
      IF(NE .GT. IK) NE=NE-IK                                           IMPU0890
65    TX=TX+AL(NE)                                                      IMPU0900
      PIEP=3.14159265/TX                                                IMPU0910
      DELD(IS1*4-1)=WRAD*DELTAT*PIEP                                    IMPU0920
      XX=0.0                                                            IMPU0930
      DO 63 II=1,IS2                                                    IMPU0940
      I=IS1+II                                                          IMPU0950
      NE=I-1                                                            IMPU0960
      IF(ICP.LE.0) GO TO 66                                             IMPU0970
      IF(I .GT. IK) I=I-IK                                              IMPU0980
66    IF(NE .GT. IK) NE=NE-IK                                           IMPU0990
      XX=XX+AL(NE)                                                      IMPU1000
      DELD(I*4-2)=WRAD*DELTAT*SIN(PIEP*XX)                              IMPU1010
63    DELD(I*4-1)=WRAD*DELTAT*PIEP*COS(PIEP*XX)                         IMPU1020
61    CONTINUE                                                          IMPU1030
60    IF(NBCOND .EQ.0) GO TO 43                                         IMPU1040
      DO 40 I=1,NBCOND                                                  IMPU1050
      JT4=NODEB(I)*4                                                    IMPU1060
      DELD(JT4-3)=0.0                                                   IMPU1070
      IF(NBC(I).EQ.1 .OR. NBC(I).EQ.2) DELD(JT4-1)=0.0                  IMPU1080
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      IF(NBC(I).EQ.2 .OR. NBC(I).EQ.3) DELD(JT4-2)=0.0                  IMPU1090
   40 CONTINUE                                                          IMPU1100
   43 CONTINUE                                                          IMPU1110
      IF(ICP.LE.0) GO TO 45                                             IMPU1120
      DO 44 K=1,4                                                       IMPU1130
      DISP(IK*4+K)=DISP(K)                                              IMPU1140
   44 DELD(IK*4+K)=DELD(K)                                              IMPU1150
   45 CONTINUE                                                          IMPU1160
      RETURN                                                            IMPU1170
     END                                                                IMPU1180
```

```
      SUBROUTINE LOADEQ(AL,AXG,AWG,TBEGIN,TFINAL)
C     TO FIND GENERALIZED NODAL LOAD AND EXTERNALLY-APPLIED LOAD TRANS-
C     FORMATION MATRICES
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION FM(8,2),AL(1),AXG(1),AWG(1),A(8,8),LMI(8),MMI(8)
     *,FMA(8,2),FMB(8,2),BNG(51)
      COMMON/MAT/YOUNG(3,6),DS(3,6),SNO(3,5,6),NSFL(3,6),P(3,6),NLAY
      COMMON /FG/ IK,IKK,ICP,LREF,NOGA,NFL,NI,ICOL(205),INUM(205)
     *,NBCOND,NBC(7),NODEB(7),KROW(8),NDEX(8),NIRREG
      COMMON/FC/ Y(51),Z(51),ANG(51),H(51,3)
      COMMON /FORCE/ T1,AMP1FV,AMP1FW,T2,AMP2FV,AMP2FW,SLOPEV,SLOPEW,
     *AMPFV,AMPFW,ETA(4),RTOV(4),RTOW(4),RTO2V(4),RTO2W(4),RTO3V(4),
     *RTO3W(4),FM1(4,8,2),FM2(2,4,8,2),FM3A(2,4,8,2),FM3B(2,4,8,2),
     *NOFT1,NOFT2,NOFT3,JELEM(4),NSTF2(4),NELF2(4),NSTF3(4),NELF3(4)
      COMMON/BOUN/ YK(51),NBCONB,NBCB(7),NODBB(7),MK(51),ROT(5,2)
     *,XDIST(6),DROT(50),NODP(6)
      COMMON /TAM/ MKE(51)
      COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      COMMON /BR/ NVEC(51,2) , LMT(51)
      SIN(Q)=DSIN(Q)
      COS(Q)=DCOS(Q)
      ATAN(Q)=DATAN(Q)
      IF(TFINAL .EQ. 0.0) RETURN
      WRITE(MWRITE,47) TBEGIN,TFINAL
47    FORMAT('0   STARTING TIME OF FORCING FUNCTION (SEC) =',E15.6,/,
     *'     STOPPING TIME OF FORCING FUNCTION (SEC) =',E15.6)
      WRITE(MWRITE,440) TBEGIN,AMP1FV,AMP1FW
  440 FORMAT('0AT TIME',D15.6,'  TANGENTIAL FORCE=',D15.6,5X,' NORMAL FO
     @RCE=',D15.6,/)
      READ(MREAD,6) NOFT1,NOFT2,NOFT3
6     FORMAT(3I5)
    7 FORMAT(I5,3D15.6)
    8 FORMAT(2I5,2D15.6)
      IF(NOFT1 .EQ. 0) GO TO 54
      WRITE(MWRITE,1001)
 1001 FORMAT('0DESCRIPTION OF POINT FORCES:')
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      WRITE(MWRITE,1005)
 1005 FORMAT('OELEMENT',13X,'S COORDINATE',12X,'RTOV',16X,'RTOW')
       READ(MREAD,7) (JELEM(I),ETA(I),RTOV(I),RTOW(I),I=1,NOFT1)
      WRITE(MWRITE,1000)  (JELEM(I),ETA(I),RTOV(I),RTOW(I),I=1,NOFT1)
 1000 FORMAT(' ',I4,10X,3D20.6)
       DO  100 I=1,NOFT1
       NE=JELEM(I)
       SL=ETA(I)
      L= MKE(NE)  -1
      K1 = NVEC(NE,1)
      K2 = NVEC(NE,2)
      P5=Z(K2)-Z(K1)
      P6=Y(K2)-Y(K1)
       P7=ANG(K2   )-ANG(K1)
      IF(YK(NE).EQ.1.0)  P7=ANG(K2)  - ROT(L,2)-ANG(K1)
      IF(YK(NE).EQ.1.0.AND.ROT(L,1).EQ.0.0)  P7=ROT(L,2)+ANG(K2)-ANG(K1)
      IF(YK(NE).EQ.2.0)   P7= ANG(K2)-  DROT(NE)  - ANG(K1)
      IF(YK(NE).EQ.3.0)  P7=ROT(L,2)+ANG(K2)-DROT(NE)-ANG(K1)
      PIE= 3.141592653589793D+00
      PIE2= 2.0*PIE
      PIE32= 1.5 *PIE
      ANG2=ANG(K2)
      ANG1=ANG(K1)
      IF(YK(NE).EQ.1.0.AND.ROT(L,1).EQ.0.0)ANG(K2)=ROT(L,2)+ANG(K2)
      IF(YK(NE).EQ.1.0.AND.ROT(L   ,1).EQ.1.0)ANG(K1)=ROT(L   ,2)+ANG(K1)
      IF(YK(NE).EQ.2.0)  ANG(K1)=  DROT(NE)  + ANG(K1)
      IF(YK(NE).EQ.3.0)  ANG(K2)=  ROT(L,2)+ANG(K2)
      IF(YK(NE).EQ.3.0)  ANG(K1)=  DROT(NE)+ANG(K1)
      APHA = PIE / 2.0
      IF(P5.LT.0.0)  APHA= -APHA
      IF(P6.NE.0.0)  APHA=  ATAN(P5/P6)
      IF(P6.LT.0.0.AND.P5.LT.0.0)APHA=APHA-PIE
       IF(P6.LT.0.0 .AND. P5.GE.0.0)  APHA=APHA+PIE
       BNG(NE+1)=ANG(K2   )
       BNG(NE)=ANG(K1)
      IF(P7.GT.(PIE32).AND.APHA.LT.0.0)  BNG(NE+1)=ANG(K2)-PIE2
```

```
      IF(P7.GT.(PIE32 ).AND.APHA.GT.0.0)  BNG(NE)=ANG(K1)+PIE2          LODQ0730
      IF(P7.LT.(-PIE32 ).AND.APHA.GT.0.0)  BNG(NE+1)=ANG(K2)   +PIE2    LODQ0740
      IF(P7.LT.(-PIE32 ).AND.APHA.LT.0.0)  BNG(NE)=ANG(K1)-PIE2         LODQ0750
       BZER=BNG(NE)-APHA                                                LODQ0760
       B1=(-2.*BNG(NE+1)-4.*BNG(NE)+6.*APHA)/AL(NE)                     LODQ0770
       B2=(3.*BNG(NE+1)+3.*BNG(NE)-6.*APHA)/AL(NE)**2                   LODQ0780
      ANG(K2)= ANG2                                                     LODQ0790
      ANG(K1)= ANG1                                                     LODQ0800
      DO 400 K=1,8                                                      LODQ0810
       DO 400 J=1,8                                                     LODQ0820
  400 A(K,J) = 0.0                                                      LODQ0830
       A(1,1)= COS(BNG(NE)-APHA)                                        LODQ0840
       A(1,2)= SIN(BNG(NE)-APHA)                                        LODQ0850
       A(2,1)=-SIN(BNG(NE)-APHA)                                        LODQ0860
       A(2,2)= COS(BNG(NE)-APHA)                                        LODQ0870
       A(3,3)=1.                                                        LODQ0880
       A(5,1)=COS(BNG(NE+1)-APHA)                                       LODQ0890
       A(5,2)=SIN(BNG(NE+1)-APHA)                                       LODQ0900
       A(5,3)=P6*SIN(BNG(NE+1))-P5*COS(BNG(NE+1))                       LODQ0910
       A(6,1)=-SIN(BNG(NE+1)-APHA)                                      LODQ0920
       A(6,2)=COS(BNG(NE+1)-APHA)                                       LODQ0930
       A(6,3)=P6*COS(BNG(NE+1))+P5*SIN(BNG(NE+1))                       LODQ0940
       A(7,3)=1.                                                        LODQ0950
       A(4,4)=1.                                                        LODQ0960
       A(5,4)=AL(NE)                                                    LODQ0970
       A(5,7)=AL(NE)**2                                                 LODQ0980
       A(5,8)=AL(NE)**3                                                 LODQ0990
       A(6,5)=AL(NE)**2                                                 LODQ1000
       A(6,6)=AL(NE)**3                                                 LODQ1010
       P8=B1+2.*B2*AL(NE)                                               LODQ1020
       A(7,4)=AL(NE)*P8                                                 LODQ1030
       A(7,5)=2.*AL(NE)                                                 LODQ1040
       A(7,6)=3.*AL(NE)**2                                              LODQ1050
       A(7,7)=AL(NE)**2*P8                                              LODQ1060
       A(7,8)=AL(NE)**3*P8                                              LODQ1070
       A(8,4)=1.                                                        LODQ1080
```

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```
      A(8,5)=-AL(NE)**2*P8
      A(8,6)=-AL(NE)**3*P8
      A(8,7)=2.*AL(NE)
      A(8,8)=3.*AL(NE)**2
      CALL MINV(A,8,DET,LMI,MMI)
      PHI=BZER+B1*SL+B2*SL**2
      PHIP=B1+2.*B2*SL
      YZET=0.0
      ZZET=0.0
      DO 101 JJ=1,NGGA
      P2=BZER+B1*SL*AXG(JJ)+B2*(SL*AXG(JJ))**2+APHA
      YZET=YZET+COS(P2)*SL*AWG(JJ)
  101 ZZET=ZZET+SIN(P2)*SL*AWG(JJ)
      P3=YZET*SIN(PHI+APHA)-ZZET*COS(PHI+APHA)
      P4=YZET*COS(PHI+APHA)+ZZET*SIN(PHI+APHA)
      FM(1,1)=COS(PHI)
      FM(2,1)=SIN(PHI)
      FM(1,2)=-SIN(PHI)
      FM(2,2)=COS(PHI)
      FM(3,1)=P3
      FM(3,2)=P4
      FM(4,1)=SL
      FM(4,2)=0.0
      FM(5,1)=0.0
      FM(5,2)=SL**2
      FM(6,1)=0.0
      FM(6,2)=SL**3
      FM(7,1)=SL**2
      FM(7,2)=0.0
      FM(8,1)=SL**3
      FM(8,2)=0.0
      DO 102 M=1,8
      DO 102 N=1,2
      FM1(I,M,N)=0.0
      DO 102 K=1,8
  102 FM1(I,M,N)=FM1(I,M,N)+A(K,M)*FM(K,N)
```

```
100    CONTINUE
54     IF(NOFT2 .EQ. 0) GO TO 55
      WRITE(MWRITE,1010)
1010  FORMAT('ODESCRIPTION OF RECTANGULAR SHAPED FORCES:')
      WRITE(MWRITE,1011)
1011  FORMAT('OFIRST ELEMENT',5X,'NO. OF ELEMS.',10X,'RTO2V',17X,'RTO2W'
     @)
       READ(MREAD,8) (NSTF2(I),NELF2(I),RTO2V(I),RTO2W(I),I=1,NOFT2)
      WRITE(MWRITE,1015)  (NSTF2(I),NELF2(I),RTO2V(I),RTO2W(I),I=1,NOFT2)
1015  FORMAT(5X,I4,13X,I4,12X,D13.6,10X,D13.6)
       DO 200 I=1,NOFT2
       NSTAT=NSTF2(I)
       NEND=NELF2(I)
       DO 201 NN=1,NEND
       NE=(NSTAT-1)+NN
       IF(NE .GT. IK) NE=NE-IK
      L= MKE(NE) -1
      K1 = NVEC(NE,1)
      K2 = NVEC(NE,2)
      P5=Z(K2)-Z(K1)
      P6=Y(K2)-Y(K1)
       P7=ANG(K2  )-ANG(K1)
      IF(YK(NE).EQ.1.0)  P7=ANG(K2)  - ROT(L,2)-ANG(K1)
      IF(YK(NE).EQ.1.0.AND.ROT(L,1).EQ.0.0)  P7=ROT(L,2)+ANG(K2)-ANG(K1)
      IF(YK(NE).EQ.2.0)   P7= ANG(K2)-  DROT(NE)  - ANG(K1)
      IF(YK(NE).EQ.3.0)  P7=ROT(L,2)+ANG(K2)-DROT(NE)-ANG(K1)
      PIE= 3.14159265358979 3D+00
      PIE2= 2.0*PIE
      PIE32= 1.5 *PIE
      ANG2=ANG(K2)
      ANG1=ANG(K1)
      IF(YK(NE).EQ.1.0.AND.ROT(L,1).EQ.0.0)ANG(K2)=ROT(L,2)+ANG(K2)
      IF(YK(NE).EQ.1.0.AND.ROT(L   ,1).EQ.1.0)ANG(K1)=ROT(L   ,2)+ANG(K1)
      IF(YK(NE).EQ.2.0)  ANG(K1)=  DROT(NE)  + ANG(K1)
      IF(YK(NE).EQ.3.0)  ANG(K2)=  ROT(L,2)+ANG(K2)
      IF(YK(NE).EQ.3.0)  ANG(K1)=  DROT(NE)+ANG(K1)
```


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      APHA = PIE / 2.0
      IF(P5.LT.0.0) APHA= -APHA
      IF(P6.NE.0.0) APHA= ATAN(P5/P6)
      IF(P6.LT.0.0.AND.P5.LT.0.0)APHA=APHA-PIE
       IF(P6.LT.0.0 .AND. P5.GE.0.0) APHA=APHA+PIE
       BNG(NE+1)=ANG(K2  )
       BNG(NE)=ANG(K1)
      IF(P7.GT.(PIE32 ).AND.APHA.LT.0.0) BNG(NE+1)=ANG(K2)   -PIE2
      IF(P7.GT.(PIE32 ).AND.APHA.GT.0.0) BNG(NE)=ANG(K1)+PIE2
      IF(P7.LT.(-PIE32 ).AND.APHA.GT.0.0) BNG(NE+1)=ANG(K2)   +PIE2
      IF(P7.LT.(-PIE32 ).AND.APHA.LT.0.0) BNG(NE)=ANG(K1)-PIE2
       BZER=BNG(NE)-APHA
       B1=(-2.*BNG(NE+1)-4.*BNG(NE)+6.*APHA)/AL(NE)
       B2=(3.*BNG(NE+1)+3.*BNG(NE)-6.*APHA)/AL(NE)**2
      ANG(K2)= ANG2
      ANG(K1)= ANG1
      DO 401 K=1,8
       DO 401 J=1,8
  401 A(K,J) = 0.0
       A(1,1)= COS(BNG(NE)-APHA)
       A(1,2)= SIN(BNG(NE)-APHA)
       A(2,1)=-SIN(BNG(NE)-APHA)
       A(2,2)= COS(BNG(NE)-APHA)
       A(3,3)=1.
       A(5,1)=COS(BNG(NE+1)-APHA)
       A(5,2)=SIN(BNG(NE+1)-APHA)
       A(5,3)=P6*SIN(BNG(NE+1))-P5*COS(BNG(NE+1))
       A(6,1)=-SIN(BNG(NE+1)-APHA)
       A(6,2)=COS(BNG(NE+1)-APHA)
       A(6,3)=P6*COS(BNG(NE+1))+P5*SIN(BNG(NE+1))
       A(7,3)=1.
       A(4,4)=1.
       A(5,4)=AL(NE)
       A(5,7)=AL(NE)**2
       A(5,8)=AL(NE)**3
       A(6,5)=AL(NE)**2
```

```
      A(6,6)=AL(NE)**3                                                  LODQ2170
      P8=B1+2.*B2*AL(NE)                                                LODQ2180
      A(7,4)=AL(NE)*P8                                                  LODQ2190
      A(7,5)=2.*AL(NE)                                                  LODQ2200
      A(7,6)=3.*AL(NE)**2                                               LODQ2210
      A(7,7)=AL(NE)**2*P8                                               LODQ2220
      A(7,8)=AL(NE)**3*P8                                               LODQ2230
      A(8,4)=1.                                                         LODQ2240
      A(8,5)=-AL(NE)**2*P8                                              LODQ2250
      A(8,6)=-AL(NE)**3*P8                                              LODQ2260
      A(8,7)=2.*AL(NE)                                                  LODQ2270
      A(8,8)=3.*AL(NE)**2                                               LODQ2280
      CALL MINV(A,8,DET,LMI,MMI)                                        LODQ2290
      DO 202 M=1,8                                                      LODQ2300
      DO 202 N=1,2                                                      LODQ2310
  202 FM(M,N)=0.0                                                       LODQ2320
      DO 203 J=1,NOGA                                                   LODQ2330
      ZET=AL(NE)*AXG(J)                                                 LODQ2340
      PHIP=B1+2.*B2*ZET                                                 LODQ2350
      PHI=BZER+B1*ZET+B2*ZET**2                                         LODQ2360
      WET=AL(NE)*AWG(J)                                                 LODQ2370
      YZET=0.0                                                          LODQ2380
      ZZET=0.0                                                          LODQ2390
      DO 204 JJ=1,NOGA                                                  LODQ2400
      P2=BZER+B1*ZET*AXG(JJ)+B2*(ZET*AXG(JJ))**2+APHA                   LODQ2410
      YZET=YZET+COS(P2)*ZET*AWG(JJ)                                     LODQ2420
  204 ZZET=ZZET+SIN(P2)*ZET*AWG(JJ)                                     LODQ2430
      P3=YZET*SIN(PHI+APHA)-ZZET*COS(PHI+APHA)                          LODQ2440
      P4=YZET*COS(PHI+APHA)+ZZET*SIN(PHI+APHA)                          LODQ2450
      FM(1,1)=FM(1,1)+COS(PHI)*WET                                      LODQ2460
      FM(1,2)=FM(1,2)-SIN(PHI)*WET                                      LODQ2470
      FM(2,1)=FM(2,1)+SIN(PHI)*WET                                      LODQ2480
      FM(2,2)=FM(2,2)+COS(PHI)*WET                                      LODQ2490
      FM(3,1)=FM(3,1)+P3*WET                                            LODQ2500
      FM(4,1)=FM(4,1)+ZET*WET                                           LODQ2510
      FM(7,1)=FM(7,1)+ZET**2*WET                                        LODQ2520
```

C-3

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```
      FM(8,1)=FM(8,1)+ZET**3*WET
      FM(3,2)=FM(3,2)+P4*WET
      FM(5,2)=FM(5,2)+ZET**2*WET
      FM(6,2)=FM(6,2)+ZET**3*WET
203   CONTINUE
      DO 205 M=1,8
      DO 205 N=1,2
      FM2(I,NN,M,N)=0.0
      DO 205 K=1,8
205   FM2(I,NN,M,N)=FM2(I,NN,M,N)+A(K,M)*FM(K,N)
201   CONTINUE
200   CONTINUE
55    IF(NOFT3 .EQ. 0) RETURN
     WRITE(MWRITE,1020)
1020 FORMAT('ODESCRIPTION OF SINE SHAPED FORCES:')
     WRITE(MWRITE,1021)
1021 FORMAT('OFIRST ELEMENT',5X,'NO. OF ELEMS.',10X,'RTO3V',17X,'RTO3W'
    @)
      READ(MREAD,8) (NSTF3(I),NELF3(I),RTO3V(I),RTO3W(I),I=1,NOFT3)
     WRITE(MWRITE,1015) (NSTF3(I),NELF3(I),RTO3V(I),RTO3W(I),I=1,NOFT3)
      DO 300 I=1,NOFT3
      NSTAT=NSTF3(I)
      NEND=NELF3(I)
      DO 301 NN=1,NEND
      NE=(NSTAT-1)+NN
      IF(NE .GT. IK) NE=NE-IK
     L= MKE(NE) -1
     K1 = NVEC(NE,1)
     K2 = NVEC(NE,2)
     P5=Z(K2)-Z(K1)
     P6=Y(K2)-Y(K1)
      P7=ANG(K2  )-ANG(K1)
     IF(YK(NE).EQ.1.0) P7=ANG(K2) - ROT(L,2)-ANG(K1)
     IF(YK(NE).EQ.1.0.AND.ROT(L,1).EQ.0.0) P7=ROT(L,2)+ANG(K2)-ANG(K1)
     IF(YK(NE).EQ.2.0)  P7= ANG(K2)- DROT(NE) - ANG(K1)
     IF(YK(NE).EQ.3.0) P7=ROT(L,2)+ANG(K2)-DROT(NE)-ANG(K1)
```

```
      PIE= 3.141592653589793D+00
      PIE2= 2.0*PIE
      PIE32= 1.5 *PIE
      ANG2=ANG(K2)
      ANG1=ANG(K1)
      IF(YK(NE).EQ.1.0.AND.ROT(L,1).EQ.0.0)ANG(K2)=ROT(L,2)+ANG(K2)
      IF(YK(NE).EQ.1.0.AND.ROT(L   ,1).EQ.1.0)ANG(K1)=ROT(L   ,2)+ANG(K1)
      IF(YK(NE).EQ.2.0)  ANG(K1)= DROT(NE)  + ANG(K1)
      IF(YK(NE).EQ.3.0)  ANG(K2)= ROT(L,2)+ANG(K2)
      IF(YK(NE).EQ.3.0)  ANG(K1)= DROT(NE)+ANG(K1)
      APHA = PIE / 2.0
      IF(P5.LT.0.0)  APHA= -APHA
      IF(P6.NE.0.0)  APHA= ATAN(P5/P6)
      IF(P6.LT.0.0.AND.P5.LT.0.0)APHA=APHA-PIE
       IF(P6.LT.0.0 .AND. P5.GE.0.0)  APHA=APHA+PIE
       BNG(NE+1)=ANG(K2   )
       BNG(NE)=ANG(K1)
      IF(P7.GT.(PIE32 ).AND.APHA.LT.0.0)  BNG(NE+1)=ANG(K2)   -PIE2
      IF(P7.GT.(PIE32 ).AND.APHA.GT.0.0)  BNG(NE)=ANG(K1)+PIE2
      IF(P7.LT.(-PIE32 ).AND.APHA.GT.0.0)  BNG(NE+1)=ANG(K2)   +PIE2
      IF(P7.LT.(-PIE32 ).AND.APHA.LT.0.0)  BNG(NE)=ANG(K1)-PIE2
       BZER=BNG(NE)-APHA
       B1=(-2.*BNG(NE+1)-4.*BNG(NE)+6.*APHA)/AL(NE)
       B2=(3.*BNG(NE+1)+3.*BNG(NE)-6.*APHA)/AL(NE)**2
      ANG(K2)= ANG2
      ANG(K1)= ANG1
      DO 402 K=1,8
       DO 402 J=1,8
  402 A(K,J) = 0.0
       A(1,1)= COS(BNG(NE)-APHA)
       A(1,2)= SIN(BNG(NE)-APHA)
       A(2,1)=-SIN(BNG(NE)-APHA)
       A(2,2)= COS(BNG(NE)-APHA)
       A(3,3)=1.
       A(5,1)=COS(BNG(NE+1)-APHA)
       A(5,2)=SIN(BNG(NE+1)-APHA)
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      A(5,3)=P6*SIN(BNG(NE+1))-P5*COS(BNG(NE+1))                        LODQ3250
      A(6,1)=-SIN(BNG(NE+1)-APHA)                                       LODQ3260
      A(6,2)=COS(BNG(NE+1)-APHA)                                        LODQ3270
      A(6,3)=P6*COS(BNG(NE+1))+P5*SIN(BNG(NE+1))                        LODQ3280
      A(7,3)=1.                                                         LODQ3290
      A(4,4)=1.                                                         LODQ3300
      A(5,4)=AL(NE)                                                     LODQ3310
      A(5,7)=AL(NE)**2                                                  LODQ3320
      A(5,8)=AL(NE)**3                                                  LODQ3330
      A(6,5)=AL(NE)**2                                                  LODQ3340
      A(6,6)=AL(NE)**3                                                  LODQ3350
      P8=B1+2.*B2*AL(NE)                                                LODQ3360
      A(7,4)=AL(NE)*P8                                                  LODQ3370
      A(7,5)=2.*AL(NE)                                                  LODQ3380
      A(7,6)=3.*AL(NE)**2                                               LODQ3390
      A(7,7)=AL(NE)**2*P8                                               LODQ3400
      A(7,8)=AL(NE)**3*P8                                               LODQ3410
      A(8,4)=1.                                                         LODQ3420
      A(8,5)=-AL(NE)**2*P8                                              LODQ3430
      A(8,6)=-AL(NE)**3*P8                                              LODQ3440
      A(8,7)=2.*AL(NE)                                                  LODQ3450
      A(8,8)=3.*AL(NE)**2                                               LODQ3460
      CALL MINV(A,8,DET,LMI,MMI)                                        LODQ3470
      DO 302 M=1,8                                                      LODQ3480
      DO 302 N=1,2                                                      LODQ3490
      FMA(M,N)=0.0                                                      LODQ3500
  302 FMB(M,N)=0.0                                                      LODQ3510
      DO 303 J=1,NOGA                                                   LODQ3520
      ZET=AL(NE)*AXG(J)                                                 LODQ3530
      PHIP=B1+2.*B2*ZET                                                 LODQ3540
      PHI=BZER+B1*ZET+B2*ZET**2                                         LODQ3550
      WET=AL(NE)*AWG(J)                                                 LODQ3560
      YZET=0.0                                                          LODQ3570
      ZZET=0.0                                                          LODQ3580
      DO 304 JJ=1,NOGA                                                  LODQ3590
      P2=BZER+B1*ZET*AXG(JJ)+B2*(ZET*AXG(JJ))**2+APHA                   LODQ3600
```

```
      YZET=YZET+COS(P2)*ZET*AWG(JJ)
304   ZZET=ZZET+SIN(P2)*ZET*AWG(JJ)
      P3=YZET*SIN(PHI+APHA)-ZZET*COS(PHI+APHA)
      P4=YZET*COS(PHI+APHA)+ZZET*SIN(PHI+APHA)
      FMA(1,1)=FMA(1,1)+COS(PHI)*WET
      FMA(2,1)=FMA(2,1)+SIN(PHI)*WET
      FMA(3,1)=FMA(3,1)+P3*WET
      FMA(4,1)=FMA(4,1)+ZET*WET
      FMA(7,1)=FMA(7,1)+ZET**2*WET
      FMA(8,1)=FMA(8,1)+ZET**3*WET
      FMA(1,2)=FMA(1,2)-SIN(PHI)*WET
      FMA(2,2)=FMA(2,2)+COS(PHI)*WET
      FMA(3,2)=FMA(3,2)+P4*WET
      FMA(5,2)=FMA(5,2)+ZET**2*WET
      FMA(6,2)=FMA(6,2)+ZET**3*WET
      FMB(1,1)=FMB(1,1)+COS(PHI)*ZET*WET/AL(NE)
      FMB(2,1)=FMB(2,1)+SIN(PHI)*ZET*WET/AL(NE)
      FMB(3,1)=FMB(3,1)+P3*ZET*WET/AL(NE)
      FMB(4,1)=FMB(4,1)+ZET**2*WET/AL(NE)
      FMB(7,1)=FMB(7,1)+ZET**3*WET/AL(NE)
      FMB(8,1)=FMB(8,1)+ZET**4*WET/AL(NE)
      FMB(1,2)=FMB(1,2)-SIN(PHI)*ZET*WET/AL(NE)
      FMB(2,2)=FMB(2,2)+COS(PHI)*ZET*WET/AL(NE)
      FMB(3,2)=FMB(3,2)+P4*ZET*WET/AL(NE)
      FMB(5,2)=FMB(5,2)+ZET**3*WET/AL(NE)
      FMB(6,2)=FMB(6,2)+ZET**4*WET/AL(NE)
303   CONTINUE
      DO 305 M=1,8
      DO 305 N=1,2
      FM3A(I,NN,M,N)=0.0
      FM3B(I,NN,M,N)=0.0
      DO 305 K=1,8
      FM3A(I,NN,M,N)=FM3A(I,NN,M,N)+A(K,M)*FMA(K,N)
305   FM3B(I,NN,M,N)=FM3B(I,NN,M,N)+A(K,M)*FMB(K,N)
301   CONTINUE
300   CONTINUE
      RETURN
      END
```

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```
      SUBROUTINE LOADFT(TIME,NREADF,FMECH,AL)
C     TO FIND THE GENERALIZED NODAL LOAD VECTOR EQUIVALENT TO THE
C     EXTERNALLY-APPLIED LOAD
      IMPLICIT REAL*8(A-H,O-Z)
     DIMENSION  DUMMY(8,8)
      DIMENSION FMECH(205),ELF(8),AL(50)
     COMMON/MAT/YOUNG(3,6),DS(3,6),SNO(3,5,6),NSFL(3,6),P(3,6),NLAY
     COMMON /FG/ IK,IKK,ICP,LREF,NOGA,NFL,NI,ICOL(205),INUM(205)
    *,NBCOND,NBC(7),NODEB(7),KROW(8),NDEX(8),NIRREG
      COMMON /FORCE/ T1,AMP1FV,AMP1FW,T2,AMP2FV,AMP2FW,SLOPEV,SLOPEW,
    *AMPFV,AMPFW,ETA(4),RTOV(4),RTOW(4),RTO2V(4),RTO2W(4),RTO3V(4),
    *RTO3W(4),FM1(4,8,2),FM2(2,4,8,2),FM3A(2,4,8,2),FM3B(2,4,8,2),
    *NOFT1,NOFT2,NOFT3,JELEM(4),NSTF2(4),NELF2(4),NSTF3(4),NELF3(4)
     COMMON/BOUN/ YK(51),NBCONB,NBCB(7),NODBB(7),MK(51),ROT(5,2)
    *,XDIST(6),DROT(50),NODP(6)
      COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      SIN(Q)=DSIN(Q)
      IF(NREADF .GT. 0) GO TO 50
 51   READ(MREAD,52) T2,AMP2FV,AMP2FW
 52   FORMAT(3E15.6)
     WRITE(MWRITE,400) T2,AMP2FV,AMP2FW
 400 FORMAT('0AT TIME',D15.6,'  TANGENTIAL FORCE=',D15.6,5X,' NORMAL FO
    @RCE=',D15.6,/)
      NREADF=1
      SLOPEV=(AMP2FV-AMP1FV)/(T2-T1)
      SLOPEW=(AMP2FW-AMP1FW)/(T2-T1)
 50   IF(TIME .LE. T2) GO TO 53
      T1=T2
      AMP1FV=AMP2FV
      AMP1FW=AMP2FW
      GO TO 51
 53   AMPFV=AMP1FV+(TIME-T1)*SLOPEV
      AMPFW=AMP1FW+(TIME-T1)*SLOPEW
      DO 57 I=1,NI
 57   FMECH(I)=0.0
      IF(NOFT1 .EQ. 0) GO TO 54
```

```
      DO 100 I=1,NOFT1
      NE=JELEM(I)
      FMV=AMPFV*RTOV(I)
      FMW=AMPFW*RTOW(I)
      DO 101 J=1,8
101    ELF(J)=FM1(I,J,1)*FMV+FM1(I,J,2)*FMW
     IF(YK(NE).EQ.0.0) GO TO 100
          CALL ROTAT(2,DUMMY,ELF,NE)
100   CALL ASSEF(NE,IK,ELF,FMECH,ICP)
54    IF(NOFT2 .EQ. 0) GO TO 55
      DO 200 I=1,NOFT2
      NSTAT=NSTF2(I)
      NEND=NELF2(I)
      FMV=AMPFV*RTO2V(I)
      FMW=AMPFW*RTO2W(I)
      DO 201 NN=1,NEND
      NE=(NSTAT-1)+NN
      IF(NE .GT. IK) NE=NE-IK
      DO 202 J=1,8
202   ELF(J)=FM2(I,NN,J,1)*FMV+FM2(I,NN,J,2)*FMW
     IF(YK(NE).EQ.0.0) GO TO 201
          CALL ROTAT(2,DUMMY,ELF,NE)
201   CALL ASSEF(NE,IK,ELF,FMECH,ICP)
200   CONTINUE
55    IF(NOFT3 .EQ. 0) GO TO 90
      DO 300 I=1,NOFT3
      NSTAT=NSTF3(I)
      NEND=NELF3(I)
      TX=0.0
      DO 303 NN=1,NEND
      NE=(NSTAT-1)+NN
      IF(NE .GT. IK) NE=NE-IK
303   TX=TX+AL(NE)
      PIEP=3.14159265/TX
      FMV=AMPFV*RTO3V(I)
      FMW=AMPFW*RTO3W(I)
```


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```
      FMW1=0.0
      FMV1=0.0
      XX=0.0
      DO 301 NN=1,NEND
      NE=(NSTAT-1)+NN
      IF(NE .GT. IK) NE=NE-IK
      XX=XX+AL(NE)
      X=PIEP*XX
      FMW2=SIN(X)*FMW
      FMV2=SIN(X)*FMV
      AFSW=FMW1
      BFSW=(FMW2-FMW1)
      AFSV=FMV1
      BFSV=FMV2-FMV1
      FMW1=FMW2
      FMV1=FMV2
      DO 302 J=1,8
302   ELF(J)=FM3A(I,NN,J,1)*AFSV+FM3A(I,NN,J,2)*AFSW+
     *FM3B(I,NN,J,1)*BFSV+FM3B(I,NN,J,2)*BFSW
      IF(YK(NE).EQ.0.0) GO TO 301
          CALL ROTAT(2,DUMMY,ELF,NE)
301   CALL ASSEF(NE,IK,ELF,FMECH,ICP)
300   CONTINUE
90    IF(NBCOND .EQ. 0) RETURN
      DO 91 I=1,NBCOND
      JT4=NODEB(I)*4
      FMECH(JT4-3)=0.0
      IF(NBC(I).EQ.1 .OR. NBC(I).EQ.2) FMECH(JT4-1)=0.0
      IF(NBC(I).EQ.2 .OR. NBC(I).EQ.3) FMECH(JT4-2)=0.0
91    CONTINUE
56    RETURN
      END
```

```
      SUBROUTINE PRINT(IT,TIME,HINN,HOUT,APDEN,SPRIN,BMASS,C2,NQR,
     *CINETO,BEP,WET,NV,ES,ASFL,SNS,NV1,NV2,NV3)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION ASFL(NV1,3,NV2,NV3),SNS(NV1,3,NV2,NV3)
      DIMENSION AB(18), ES(3,6,6)
      DIMENSION COPY(51),COPZ(51),BEPS(3)
     *,BEP(50,3,3,8),WET(50,3),HINN(50,3),HOUT(50,3),FKTP(3)
     *,FQREF(204),BMASS(1),CINE(205),SPRIN(1),FAILI(50),FAILO(50)
      COMMON/VQ/ FLVA(205),DISP(205),DELD(205),BINP(50,3),BIMP(50,3)
      COMMON/FC/ Y(51),Z(51),ANG(51),H(51,3)
      COMMON /FRAG/ FH(3),FMASS(3),FMOI(3),UNK(3),CR(3),FCGU(3),FCGW(3)
     *,ALFA(3),DFCGU(3),DFCGW(3),DALFA(3),TREL,FKT(3),DELTAT,NF,MIMP
      COMMON /EP/ EPSI(50),EPSO(50)
      COMMON /FG/ IK,IKK,ICP,LREF,NOGA,NFL,NI,ICOL(205),INUM(205)
     *,NBCOND,NBC(7),NODEB(7),KROW(8),NDEX(8),NIRREG
      COMMON/MAT/YOUNG(3,6),DS(3,6),SNO(3,5,6),NSFL(3,6),P(3,6),NLAY
      COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      COMMON /TAM/ MKE(51)
      SIN(Q)=DSIN(Q)
      COS(Q)=DCOS(Q)
      DO 700 I=1,NI
700   CINE(I)=0.0
      CALL OMULT(BMASS,DELD,ICOL,NI,CINE,KROW,NDEX,NIRREG)
      CINET=0.0
      DO 701 I=1,NI
701   CINET=CINET+DELD(I)*CINE(I)
      CINET=CINET*C2
      IF(IT.EQ.0.AND.NV.NE.0) CINETO=CINET
      ELAST=0.0
      DO 702 IR=1,IK
      I=MKE(IR)
      NLAP = NLAY
      IF(MKE(IR).GT.1) NLAP = 1
      DO 703 J=1,NOGA
      SUM=0.0
      DO 801 M=1,NLAP
```


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```
      NSFLM=NSFL(M,I)
      DO 801 N=1,NFL
      STRS=0.0
       K=N+(M-1)*NFL
      DO 802 L=1,NSFLM
      LL= L+1
      AB(K)= (ES(M,L,I)-ES(M,LL,I))/ ES(M,1,I)
  802 STRS=STRS+SNS(IR,J,K,L)* AB(K)
      STRS= STRS**2
  801 SUM = SUM+STRS*ASFL(IR,J,K,NSFLM)/(AB(K)*YOUNG(M,I))
  703 ELAST= ELAST+(SUM*WET(IR,J))/2.0
 702   CONTINUE
       SPDEN=0.0
       IF(NQR .EQ. 0) GO TO 31
       DO 30 I=1,NI
 30    FQREF(I)=0.0
       CALL OMULT(SPRIN,DISP,ICOL,NI,FQREF,KROW,NDEX,NIRREG)
       DO 32 I=1,NI
 32    SPDEN=SPDEN+DISP(I)*FQREF(I)
       SPDEN=SPDEN/2.
 31    ELAST=ELAST/2.
       CFRAG=0.0
 300   CINETT=CINETO+APDEN+CFRAG
       PLAST=CINETT-CINET-ELAST-SPDEN
       WRITE(MWRITE,1) IT,TIME,CINETT,CINET,ELAST,PLAST
 1     FORMAT('-   J=',I5,'       TIME (SEC.) =',E15.6,/,
     *'    WORK INPUT INTO RING (IN.-LB.)     =',E15.6,/,
     *'    RING KINETIC ENERGY  (IN.-LB.)     =',E15.6,/,
     *'    RING ELASTIC ENERGY  (IN.-LB.)     =',E15.6,/,
     *'    RING PLASTIC WORK    (IN.-LB.)     =',E15.6)
       IF(NQR .EQ. 0) GO TO 33
       WRITE(MWRITE,34) SPDEN
 34    FORMAT('    ENERGY STORED IN THE ELASTIC RESTRAINTS (IN.-LB.)  =',
     *E15.6)
 33    DO 11 I=1,IKK
       COPY(I)=Y(I)+DISP(I*4-3)*COS(ANG(I))-DISP(I*4-2)*SIN(ANG(I))
```

```
11    COPZ(I)=Z(I)+DISP(I*4-3)*SIN(ANG(I))+DISP(I*4-2)*COS(ANG(I))
      IKP1=IK+1
      WRITE(MWRITE,2)
2     FORMAT(/,'    I ',5X,'V',11X,'W',9X,'PSI',9X,'CHI',10X,'COPY',
     *8X,'COPZ',9X,'L',11X,'M',7X,'STRAIN(IN)',4X,'STRAIN(OUT)')
50    DO 21 I=1,IK
21    WRITE(MWRITE,22)I,DISP(I*4-3),DISP(I*4-2),DISP(I*4-1),DISP(I*4),
     *COPY(I),COPZ(I),BINP(I,2),BIMP(I,2),EPSI(I),EPSO(I)
22    FORMAT(I5,9E12.4,2X,E12.4)
      IF(ICP.GT.0) GO TO 57
      WRITE(MWRITE,24) IKP1,DISP(IKP1*4-3),DISP(IKP1*4-2),
     *DISP(IKP1*4-1),DISP(IKP1*4),COPY(IKP1),COPZ(IKP1),EPSI(IKP1),
     @EPSC(IKP1)
   24 FORMAT(I5,6D12.4,24X,D12.4,D14.4)
57    CONTINUE
      RETURN
     END
```


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6.3 Additional Subroutines Needed for CIVM-JET 5B

These five (5) subroutines consist of:

MAIN

IMPACT

IMPCTE

PENTRN

PRINT

and are listed in the following:

```
C     (C)  COPYRIGHT 1978  MASSACHUSETTS INSTITUTE OF TECHNOLOGY
C     CIVM JET 5B MAIN PROGRAM FOR VARIABLE THICKNESS ARBITRARILY CURVED
C     MULTILAYER RING SUBJECTED TO FRAGMENT IMPACT
C     CIVM JET 5B HOUBOLT  OPERATOR
        IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION ASFL(20,3,3,3),GZETA(20,3,8),SNS(20,3,8,3),
     @ SNP(20,3,8,3),AEP(20,3,8),DEP(20,2,3,8)
      DIMENSION STIFK(1140),SPRIN(1140),AMASS(1140),REACK(1140)
     @,REAFK(205),REACM(1140),REAC(21)
      DIMENSION  BMASS(1140)
      DIMENSION DISUM(205)
      DIMENSION EPL2(3),EPL1(3)
      DIMENSION  RMX(51),RM(3),RMO(3), CL(3),YCG(3),SOL(205)
      DIMENSION DELDM1(205),RH(3),HZ(3),HREF(50,3,3),FLN(205),FLVM(205)
     @,QACL(205),QVEL(205),TXG(6),TWG(6),ES(3,6,6)
      DIMENSION  CINETF(3),TRANEN(3),ROTEN(3)
      DIMENSION BEPS(3,3),EPI(3),EPO(3)
      DIMENSION HDIF(3),DIS(205)
       DIMENSION HNIN(51),EFLN(6),TPRIM(3)
      DIMENSION DENS(3,6),B(6),EPS(3,5,6),SIG(3,5,6)
      DIMENSION NSBS(50),NSEL(50),AEPS(3)
      DIMENSION DISM(8) ,DELM(8), DUMMY(8,8)
      DIMENSION BIGA(6),BTIMA(6),IBIGA(6),ISTAA(6) ,ISURA(6)
      DIMENSION BI(6),BTIM(6),IBI(6),ISUR(6) , ITHR(51)
      COMMON /ACC/ QCD(205)
      COMMON/LEFT/ RMASS(51)
      COMMON/ADSP/ AZET(50),ASP(50),YSP(50),ZSP(50),LKK(50,11)
      COMMON/IMPT/ VEL(102),IMCO,JVEL(51)
      COMMON/TIAT/ TAII, IMCOU
      COMMON/HIT/ TNJ(6) ,MIRP
      COMMON /ML/ MNEL(6),MATT(6)
      COMMON/MAT/YOUNG(3,6),DS(3,6),SNO(3,5,6),NSFL(3,6),P(3,6),NLAY
      COMMON /FG/ IK,IKK,ICP,LREF,NOGA,NFL,NI,ICOL(205),INUM(205)
     *,NBCOND,NBC(7),NODEB(7),KROW(8),NDEX(8),NIRREG
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH
       COMMON/FC/ Y(51),Z(51),ANG(51),H(51,3)
```


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```
      COMMON/VQ/ FLVA(205),DISP(205),DELD(205),BINP(50,3),BIMP(50,3)
      COMMON /EP/ EPSI(50),EPSO(50)
       COMMON/BA/ BEP(50,3,3,8),AL(50),AXG(3),AWG(3),WET(50,3),
     *CE1(50,3),CE2(50,3),CE3(50,3),CM1(50,3),CM2(50,3),CM3(50,3)
      COMMON/SC/ BIG(6),BTIME(6),IBIG(6),ISURF(6),ISTA(6)
       COMMON /ELFU/ FQREF(205),REX(4),NQR,NORP,NORU
     *,NREL(4),NRST(4),NREU(4)
      COMMON /FRAGV/ UDOT(3),WDOT(3),ADOT(3)
       COMMON /FRAG/ FH(3),FMASS(3),FMOI(3),UNK(3),CR(3),FCGU(3),FCGW(3)
     *,ALFA(3),DFCGU(3),DFCGW(3),DALFA(3),TREL,FKT(3),DELTAT,NF,MIMP
      COMMON/BOUN/YK(51),NBCONB,NBCB(7),NODBB(7),MK(51),ROT(5,2)
     *,XDIST(6),DROT(50),NODP(6)
      COMMON /BR/ NVEC(51,2), LMT(51)
      COMMON/DIS/ ANGDI(50),NEDI(50),NDIS
      COMMON /TAM/ MKE(51)
      COMMON /THI/ HTH(5)
      COMMON /TIME/ IT
       SIN(Q)=DSIN(Q)
       COS(Q)=DCOS(Q)
       ATAN(Q)=DATAN(Q)
       SQRT(Q)=DSQRT(Q)
      NV1=20
      NV2=8
      NV3=3
       MREAD=5
       MWRITE=6
       MPUNCH=7
    1 FORMAT(10I5)
2      FORMAT(3D15.6)
    3 FORMAT(3D25.16)
4      FORMAT(3D15.6/(4D15.6))
5      FORMAT(5D15.6)
301    FORMAT(I5,2D15.6)
303    FORMAT(5D15.6)
      IRRUN = 1
5555  WRITE(MWRITE,5556) IRRUN
```

```
 5556 FORMAT('1THIS IS RUN NUMBER',I5,'   FOR THIS CIVM-JET 5B SUBMITTALMAIN0730
     @')                                                                MAIN0740
       READ(MREAD,1) IK,ICP,NLAY,LREF,NOGA,NFL,MM,M1,M2,ICON            MAIN0750
      READ (MREAD,1)  (NSFL(M,1),M=1,NLAY)                              MAIN0760
       DO 201 M=1,NLAY                                                  MAIN0770
      NSFLM= NSFL(M,1)                                                  MAIN0780
  201 READ(MREAD,4) DENS(M,1),DS(M,1),P(M,1),(EPS(M,L,1),SIG(M,L,1)     MAIN0790
     *,L=1,NSFLM)                                                       MAIN0800
      READ(MREAD,2) B(1),DELTAT                                         MAIN0810
      MNEL(1)= IK                                                       MAIN0820
       IKP1=IK+1                                                        MAIN0830
       IKK=IKP1                                                         MAIN0840
       IF(ICP.GT.0) IKK=IK                                              MAIN0850
      NS= IKK                                                           MAIN0860
       NI=IKK*4                                                         MAIN0870
      MPU=1                                                             MAIN0880
C   IF CONTINUATION CARDS ARE DESIRED   REMOVE NEXT CARD   MPU=0        MAIN0890
      MPU=0                                                             MAIN0900
      PIE= 3.141592653589793D+00                                        MAIN0910
      IMCOU= 0                                                          MAIN0920
      IMCO =0                                                           MAIN0930
      NPZ1 = M1                                                         MAIN0940
      DO 7100 I=1,IKK                                                   MAIN0950
      DO 7100 J= 1,3                                                    MAIN0960
 7100 H(I,J) = 0.0                                                      MAIN0970
C   THE FOLLOWING IS THE INPUT OF THE MAIN STRUCTURE'S GEOMETRY, IF THE MAIN0980
C   USER HAS HIS OWN GENERATING ROUTINE THIS WOULD BE THE APPROPRIATE   MAIN0990
C   SPOT IN THE PROGRAM TO INSERT THE  ROUTINE.                         MAIN1000
      READ(MREAD,2) (Y(I),Z(I),ANG(I),I=1,IKK)                          MAIN1010
      READ(MREAD,5)  ((H(I,M),M=1,NLAY),I=1,IKK)                        MAIN1020
      DO 111 I=1,IKK                                                    MAIN1030
  111 ANG(I)=ANG(I)*PIE/180.0                                           MAIN1040
       IF(ICP.LE.0) GO TO 202                                           MAIN1050
       Y(IKP1)=Y(1)                                                     MAIN1060
       Z(IKP1)=Z(1)                                                     MAIN1070
       ANG(IKP1)=ANG(1)                                                 MAIN1080
```


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```
       DO 203 M=1,NLAY
 203   H(IKP1,M)=H(1,M)
 202   CONTINUE
      READ(MREAD,5300) NDIS
      NDI = NDIS
      IF(NDIS.EQ.0) GO TO 8100
      READ (MREAD,8101) (NEDI(I),ANGDI(I),I=1,NDIS)
 8101 FORMAT (4(I5,D15.6))
      DO 8102 I=1,NDIS
 8102 ANGDI(I) = (ANGDI(I)*PIE)/180.0
 8100 CONTINUE
      READ(MREAD,5300) NBR
 5300 FORMAT (2I5)
      MNSFL= NSFL(1,1)
      DO 5666 I=1,NLAY
      IF (MNSFL.LT.NSFL(I,1)) MNSFL=NSFL(I,1)
 5666 CONTINUE
      DO 5305 I= 1,IK
      MKE(I) = 1
      MK(I) = I
      LMT(I) = 0
      YK(I) = 0.0
      NVEC(I,2) = I+1
 5305 NVEC(I,1) = I
      IF (ICP.GT.0)    NVEC(IK,2) = 1
      IF(ICP.LE.0) MK(IK+1) = IK+1
      IF(NBR.NE.0) GOTO 1112
      WRITE(MWRITE,1113)
 1113 FORMAT(//,' THERE ARE NO BRANCHES CONNECTED TO THE MAIN STRUCTURE
     @,THEREFORE',/,' THE NUMBERING SYSTEM FOR NODES AND ELEMENTS REMAIN
     @S UNCHANGED')
 1112 CONTINUE
      IF (NBR.EQ.0) GO TO 5310
          CALL BRAN(NBR,DENS,EPS,SIG,B)
      DO 8888 I=1,NBR
      IF(MNSFL.LT.NSFL(1,I+1)) MNSFL= NSFL(1,I+1)
```

```
8888 CONTINUE
5310 CONTINUE
     LGSP= 0
     LSPP=0
     READ(MREAD,8200) NOP,NASP,NTERP
8200 FORMAT(3I5)
     DO 8215 I=1,IK
     DO 8215 J=1,2
8215 LKK(I,J) = 0
     IF(NOP.EQ.0) GO TO 8220
     IF(NOP.NE.2)  LGSP=1
     IF(NOP.NE.1) LSPP=1
     IF(LSPP.NE.1) GO TO 8220
     READ(MREAD,8210) (NSBS(I),NSEL(I),AZET(I),I=1,NASP)
8210 FORMAT(2I5,D15.6)
     WRITE(MWRITE,156)
 156 FORMAT('0ADDITIONAL STRAIN POINT',5X,'ELEMENT',5X,'S  COORDINATE')
     DO 8216 J= 1,NASP
     IF(NSBS(J).NE.1) GO TO 8217
     M= NSEL(J) +1
     IF(ICP.GT.0.AND.NSEL(J).EQ.IK) MK(M) = IK+1
     N= MK(M) -1
     LKK(N,1) = 1 + LKK(N,1)
     NO = LKK(N,1) + 1
     LKK(N,NO) = J
     GOTO 1400
8217 NNNN = NSBS(J)-1
     IF(NODP(NNNN).EQ.1) GOTO 8218
     NNNN= NODP(NNNN)
     N= MK(NNNN)+ NSEL(J)- 1
     GO TO 8219
8218 N= NSEL(J)
8219 LKK(N,1) = 1 + LKK(N,1)
     NO = LKK(N,1) +1
     LKK(N,NO) = J
1400 WRITE(MWRITE,145) J,N,AZET(J)
```

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  145 FORMAT(' ',9X,I5,13X,I5,7X,D15.6)
 8216 CONTINUE
 8220 CONTINUE
      IF(NDIS.EQ.0) GO TO 8140
      IF (NBR.EQ.0) GOTO  8145
      IF(NDI.EQ.0) GOTO 8145
      DO 8146 J= 1,NDI
      M= NEDI(J) +1
      N = MK(M) -1
      NEDI(J) = N
 8146 CONTINUE
 8145 WRITE(MWRITE,8111)
       WRITE(MWRITE,8120) (NEDI(I),I=1,NDIS)
 8111 FORMAT('0EACH OF THE FOLLOWING ELEMENTS HAS A SLOPE DISCONTINUITY
     @AT ITS FIRST NODE')
 8120 FORMAT(' ', 25I5)
      WRITE(MWRITE,8112) (ANGDI(L),L=1,NDIS)
 8112 FORMAT('0THE GLOBAL SLOPE (RAD.) AT EACH DISCONTINUITY EQUALS:',/,
     @(8D15.6))
      DO 8130 I= 1,NDIS
      M=NEDI(I)
      YK(M) = 2.0 + YK(M)
      L1= NVEC(M,1)
      DROT(M) = ANGDI(I) - ANG(L1)
 8130 CONTINUE
 8140 CONTINUE
       READ(MREAD,3) (AXG(K),K=1,NOGA)
       READ(MREAD,3) (AWG(K),K=1,NOGA)
       READ(MREAD,3) (TXG(K),K=1,NFL)
       READ(MREAD,3) (TWG(K),K=1,NFL)
       READ(MREAD,1) NBCOND, (NBC(I),NODEB(I),I=1,NBCOND)
      IF (NBR.EQ.0) GO TO 748
      NIT = NBCOND+ 1
      NIT1 = NIT -1
      NBCOND= NBCOND+NBCONB
      IF (NBCONB.EQ.0) GO TO 751
```

```
      DO 750 LOP= 1,NBCONB
      NBC(NIT1 + LOP) = NBCB(LOP)
  750 NODEB(NIT1 + LOP) = NODBB(LOP)
  751 IF (NIT1.EQ.0) GO TO 748
      DO 753 LOP = 1,NIT1
      NTI = NODEB(LOP)
  753 NODEB(LOP) = MK(NTI)
  748 CONTINUE
       READ(MREAD,1) NQR,NORP,NORU
           CALL IDENT(NQR,B,DENS,EPS,SIG,NBR)
      WRITE(MWRITE,402)
  402 FORMAT(///,' GAUSSIAN STATIONS AND WEIGHTS:')
      WRITE(MWRITE,400) (L,AXG(L),L, AWG(L),L=1,NOGA)
      WRITE(MWRITE,401) (L,TXG(L),L,TWG(L),L=1,NFL)
  400 FORMAT(' ',12X,'AXG',I3,2X,'=',F20.15,8X,'AWG',I3,2X,'=',F20.15)
  401 FORMAT(' ',12X,'TXG',I3,2X,'=',F20.15,8X,'TWG',I3,2X,'=',F20.15)
C   FOR MEMBRANE SET TXG=0.0 AND TWG=2.0 FOR ONE DEPTHWISE STATION
      NBR1 = NBR+1
      DO 651 K=1,NBR1
      NLAP= NLAY
      IF(K.GT.1)   NLAP=1
      DO 76 M=1,NLAP
      NSFLM=NSFL(M,K)
      ES(M,1,K)= SIG(M,1,K)/EPS(M,1,K)
       IF(NSFLM-1) 77,77,78
 78    DO 79 L=2,NSFLM
   79 ES(M,L,K)=(SIG(M,L,K)-SIG(M,L-1,K))/(EPS(M,L,K)-EPS(M,L-1,K))
   77 ES(M,NSFLM+1,K) = 0.0
       DO 80 L=1,NSFLM
   80 SNO(M,L,K) = ES(M,1,K)*EPS(M,L,K)
      YOUNG(M,K)= ES(M,1,K)
   76 CONTINUE
  651 CONTINUE
      IC = 0
       DO 70 IR=1,IK
      IF(YK(IR).EQ.1.0.OR.YK(IR).EQ.3.0) IC=IC+1
```


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```
      L1= NVEC(IR,1)
      L2 = NVEC(IR,2)
      NLAP= NLAY
      IF(MKE(IR).GT.1) NLAP=1
       DO 70 J=1,NOGA
      DO 71 M=1,NLAP
      IF(YK(IR).NE.1.0.AND.YK(IR).NE.3.0) GOTO 600
      IF (ROT(IC,1).EQ.0.0) GO TO 610
      RH(M)= HTH(IC)* (1.0-AXG(J))+H(L2,M)*AXG(J)
      GO TO 71
  610 RH(M)= H(L1,M)* (1.0-AXG(J))+ HTH(IC)*AXG(J)
      GO TO 71
  600 RH(M) = H(L1,M)*(1.0-AXG(J))+H(L2,M)*AXG(J)
   71 CONTINUE
       HZ(1)=RH(1)/2.
      IF(NLAP.EQ.1) GO TO 72
       DO 73 M=2,NLAY
 73    HZ(M)=HZ(M-1)+(RH(M)+RH(M-1))/2.
 72    CONTINUE
       CM1(IR,J)=0.0
       CM2(IR,J)=0.0
       CM3(IR,J)=0.0
       CE1(IR,J)=0.0
       CE2(IR,J)=0.0
       CE3(IR,J)=0.0
      I= MKE(IR)
      DO 74 M=1,NLAP
       HREF(IR,J,M)=HZ(M)-HZ(LREF)
      CM1(IR,J)=CM1(IR,J)+DENS(M,I)*B(I)*RH(M)
      CM2(IR,J)=CM2(IR,J)-DENS(M,I)*B(I)*RH(M)*HREF(IR,J,M)
      CM3(IR,J) =CM3(IR,J)+DENS(M,I)*B(I)*(RH(M)**3/12.
     *+HREF(IR,J,M)**2*RH(M))
C     FOR MEMBRANE SET CE2 AND CE3 = 0.0
      CE1(IR,J)=CE1(IR,J)+YOUNG(M,I)*B(I)*RH(M)
      CE2(IR,J) = CE2(IR,J)+YOUNG(M,I)*B(I)*RH(M)*HREF(IR,J,M)
      CE3(IR,J) = CE3(IR,J)+YOUNG(M,I)*B(I)*(RH(M)**3/12.0
```

```
     *+HREF(IR,J,M)**2*RH(M))                                         MAIN2890
      NSFLM=NSFL(M,I)                                                 MAIN2900
      DO 75 N=1,NFL                                                   MAIN2910
      K=N+(M-1)*NFL                                                   MAIN2920
      GFL=RH(M)*TWG(N)*B(I)/2.0                                       MAIN2930
      GZETA(IR,J,K)=RH(M)*TXG(N)/2.+HREF(IR,J,M)                      MAIN2940
      DO 75 L=1,NSFLM                                                 MAIN2950
      ASFL(IR,J,K,L)= GFL*(ES(M,L,I)-ES(M,L+1,I))/ES(M,1,I)           MAIN2960
   75 CONTINUE                                                        MAIN2970
   74 CONTINUE                                                        MAIN2980
   70 CONTINUE                                                        MAIN2990
      IF(NBR.NE.0) GOTO 218                                           MAIN3000
      DO 15 I=1,8                                                     MAIN3010
   15 ICOL(I)=1                                                       MAIN3020
      IKM1=IK-1                                                       MAIN3030
      IF(ICP.GT.0) GO TO 17                                           MAIN3040
      DO 16 I=3,IKP1                                                  MAIN3050
      IK4=I*4                                                         MAIN3060
      IK3=IK4-1                                                       MAIN3070
      IK2=IK4-2                                                       MAIN3080
      IK1=IK4-3                                                       MAIN3090
      JJ=(I-1)*4-3                                                    MAIN3100
      ICOL(IK1)=JJ                                                    MAIN3110
      ICOL(IK2)=JJ                                                    MAIN3120
      ICOL(IK3)=JJ                                                    MAIN3130
      ICOL(IK4)=JJ                                                    MAIN3140
   16 CONTINUE                                                        MAIN3150
      GO TO 19                                                        MAIN3160
   17 DO 18 I=3,IKM1                                                  MAIN3170
      IK4=I*4                                                         MAIN3180
      IK3=IK4-1                                                       MAIN3190
      IK2=IK4-2                                                       MAIN3200
      IK1=IK4-3                                                       MAIN3210
      JJ=(I-1)*4-3                                                    MAIN3220
      ICOL(IK1)=JJ                                                    MAIN3230
      ICOL(IK2)=JJ                                                    MAIN3240
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```
      ICOL(IK3)=JJ
      ICOL(IK4)=JJ
18    CONTINUE
      ICOL(IK*4)=1
      ICOL(IK*4-1)=1
      ICOL(IK*4-2)=1
      ICOL(IK*4-3)=1
19    CONTINUE
 218 INUM(1)=1
      DO 99 I=2,NI
99    INUM(I)=I-ICOL(I-1)+INUM(I-1)
      DO 990 I=1,NI
990   INUM(I)=INUM(I)-ICOL(I)
      NIRREG=0
      INDEX=0
      ISET=1
      DO 116 I=1,NI
      L=ICOL(I)
      IF(ICOL(I)-ISET) 117,116,119
119   ISET=ICOL(I)
      GO TO 116
117   NIRREG=NIRREG+1
      IF(NIRREG-NI/2)711,711,90
711   KROW(NIRREG)=I
      NDEX(NIRREG)=INDEX
116   INDEX=INDEX+I-L
90    ISIZE=NI+INUM(NI)
      WRITE(MWRITE,91) ISIZE
91    FORMAT(/,'   SIZE OF ASSEMBLED MASS OR STIFFNESS MATRIX=',I5)
     IF(ISIZE.LE.2060) GOTO 6012
     WRITE(MWRITE,6011)
6011 FORMAT('0THE SIZE OF THE STIFFNESS MATRIX HAS EXCEEDED 2060.  THIS
    @ RUN HAS BEEN TERMINATED.  CHANGE DIMENSION OF STIFK IN',/,' MAIN
    @,ELMPB,AND TSTEP.  ALSO CHANGE DIMENSIONS FOR AMASS,BMASS,AND SPRI
    @N')
     GOTO 150
```

```
6012 CONTINUE
     WRITE(MWRITE,7850)
7850 FORMAT(//,' LUMPED MASS MATRIX FOR EACH ELEMENT:',//)
     ELMPB=1.0
          CALL   ELMPP(AMASS,STIFK,ISIZE,AEP,DEP,NV1,REACK,REACM,ELMPB)
     DO 1261 IR=1,IKK
     J= IR*4-3
     K= INUM(J)+J
     RMASS(IR)= AMASS(K)
     SOL(J)= AMASS(K)
     K= INUM(J+1)+J+1
     SOL(J+1)  = AMASS(K)
     K= INUM(J+2)+J+2
     SOL(J+2)  = AMASS(K)
     K= INUM(J+3)  +J+3
     SOL(J+3)  = AMASS(K)
1261 CONTINUE
     WRITE(MWRITE,7836)
     WRITE(MWRITE,7837)  (SOL(L),L=1,NI)
7836 FORMAT(//,' THE TRANSLATIONAL AND ROTATIONAL MASSES AT EACH NODE A
    @RE:')
7837 FORMAT(' ',4D25.15)
      DO 23 L=1,ISIZE
23    SPRIN(L)=0.0
      IF  (NQR .EQ. 0)  GO TO 22
      CALL QREM(AL,AXG,AW3,SPRIN)
     DO 360 I=1,ISIZE
 360 REACK(I)= REACK(I)+ SPRIN(I)
 22  CONTINUE
     IF  (NBCOND.EQ.0) GOTO 93
      DO 92 I=1,NBCOND
      JT4=NODEB(I)*4
      JT4M3=JT4-3
      JT4M2=JT4-2
      JT4M1=JT4-1
      CALL  ERC(JT4M3,AMASS,NI,ICOL,INUM)
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      IF(NBC(I).EQ.1.OR.NBC(I).EQ.2) CALL ERC(JT4M1,AMASS,NI,ICOL,INUM)
      IF(NBC(I).EQ.2.OR.NBC(I).EQ.3) CALL ERC(JT4M2,AMASS,NI,ICOL,INUM)
      IF(NQR.EQ.0) GOTO 92
       CALL ERC(JT4M3,SPRIN,NI,ICOL,INUM)
       IF(NBC(I).EQ.1.OR.NBC(I).EQ.2) CALL ERC(JT4M1,SPRIN,NI,ICOL,INUM)
       IF(NBC(I).EQ.2.OR.NBC(I).EQ.3) CALL ERC(JT4M2,SPRIN,NI,ICOL,INUM)
   92 CONTINUE
   93 CONTINUE
      WRITE(MWRITE,7851)
 7851 FORMAT(//,' THE ASSEMBLED MASS MATRIX:',//)
      WRITE(MWRITE,7852) (AMASS(L),L=1,ISIZE)
 7852 FORMAT(' ',8D15.6)
      WRITE(MWRITE,7853)
 7853 FORMAT(//,' THE ASSEMBLED STIFFNESS MATRIX:',//)
      WRITE(MWRITE,7852) (STIFK(L),L=1,ISIZE)
      DO 948 I=1,ISIZE
  948 BMASS(I) = AMASS(I)
            CALL FAC(BMASS,ICOL,KROW,NDEX,IDET,MWRITE,NI,NIRREG,INUM)
            CALL TSTEP(BMASS,STIFK,DELTAT)
      DO 953 I=1,ISIZE
  953 BMASS(I) = AMASS(I)
      WRITE(MWRITE,52) DELTAT
   52 FORMAT(/,' TIME STEP SIZE USED IN PROGRAM (SEC)=',D15.6)
      DO 8951 J=1,NOGA
 8951 EPL2(J)= 0.0
      EPAS2= 0.0
      BIGL=0.0
      BIGAL=0.0
      IBIGAL=0
      IBIGL=0
      ISURFL=0
      ISURAL=0
      ISTAL =0
      ISTAAL=0
      M= NBR+1
      DO 10005 J= 1,M
```

```
      BIG(J)  = 0.0
      BIGA(J)  =  0.0
      BI(J)  = 0.0
      IBIGA(J)  =  0
      IBIG (J)  = 0
      IBI(J)  =  0
      ISTA (J)  = 0
      ISTAA(J)  = 0
      BTIME (J)  =  0.0
      BTIMA(J)  = 0.0
      BTIM (J)  =  0.0
10005 CONTINUE
       DTSQ=DELTAT**2
       C2=1./(2.*DELTAT**2)
       MCRIT=0
       IT=0
       TIME=0.0
      DO 50 I=1,NI
      DELD (I) = 0.0
   50 DISP(I)=0.0
      DO 51 IR=1,IK
      NLAP=NLAY
      IF (MKE (IR).GT. 1)  NLAP=1
      NO= MKE(IR)
      DO 51 J=1,NOGA
      BINP(IR,J) =  0.0
      BIMP (IR,J)  =0.0
      DO 51 M=1,NLAP
      NSFLM= NSFL(M,NO)
      DO 51 N=1,NFL
      K= N+(M-1)*NFL
      DO 51 L=1,NSFLM
      SNP(IR,J,K,L)=  0.0
   51 SNS(IR,J,K,L) = 0.0
      IF(ICP.LE.0)  GOTO 55
      DO 54 K=1,4
```

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      DISP(IK*4+K) = DISP(K)
   54 DELD(IK*4+K)= DELD(K)
   55 CONTINUE
      L=1
      READ(MREAD,301)        NF,EFLN(L)
      IF(EFLN(L).GT.0.0) GO TO 305
      EFLN(L)=DELTAT*SQRT(YOUNG(1,1)/DENS(1,1))
       IF(NLAY.EQ.1) GO TO 305
       DO 306 M=2,NLAY
      BOLD=DELTAT*SQRT(YOUNG(M,1)/DENS(M,1))
      IF(EFLN(L).LT.BOLD) EFLN(L) = BOLD
  306  CONTINUE
  305  CONTINUE
      IF(NBR.EQ.0) GOTO 308
      JNBR= NBR+1
      DO 307 I=2,JNBR
  307 EFLN(I)= DELTAT*SQRT(YOUNG(1,I)/DENS(1,I))
  308 CONTINUE
       DO 302 I=1,NF
      ALFA(I)= 0.0
      READ(MREAD,303)  FH(I),FCGW(I),FCGU(I),FMASS(I),FMOI(I)
      READ(MREAD,303)  UNK(I)
      READ(MREAD,303)  UDOT(I),WDOT(I),ADOT(I),TPRIM(I),CR(I)
      FKT(I)= FMASS(I)*(UDOT(I)**2+WDOT(I)**2)+FMOI(I)*ADOT(I)**2
      FKT(I)= FKT(I)/2.0
  302  CONTINUE
  310  WRITE(MWRITE,312)
      WRITE(MWRITE,313) NF,EFLN(1)
  312  FORMAT(/,'    FRAGMENT PROPERTIES',/)
  313  FORMAT(10X,'NO. OF FRAGMENTS                              =',I5,/,
     *10X,'EFFECTIVE LENGTH OF IMPACT (IN) ON MAIN STRUCTURE =',D15.6/)
       WRITE(MWRITE,314) (I,FH(I),FMASS(I),FMOI(I),FCGU(I),FCGW(I),
     *ALFA(I),UDOT(I),WDOT(I),ADOT(I),CR(I),UNK(I),FKT(I),I=1,NF)
  314  FORMAT(12X,'FRAG. NO.                          =',I5,/,
     *12X,'DIAMETER  (IN)                    =',E15.6,/,
     *12X,'WEIGHT(LBS-SEC**2/IN.)            =',E15.6,/,
```

```
     *12X,'MOMENT OF INERTIA(IN-LB-SEC**2)     =',E15.6,/,                 MAIN5050
     *12X,' CG Y COORDINATE    (IN)            =',E15.6,/,                 MAIN5060
     *12X,' CG Z COORDINATE    (IN)            =',E15.6,/,                 MAIN5070
     *12X,'ANGULAR ROTATION  (DEG)             =',E15.6,/,                 MAIN5080
     *12X,'VEL IN Y DIR  (IN/SEC)              =',E15.6,/,                 MAIN5090
     *12X,'VEL IN Z DIR  (IN/SEC)              =',E15.6,/,                 MAIN5100
     *12X,' ANGULAR VEL  (DEG/SEC)             =',E15.6,/,                 MAIN5110
     *12X,'COEFF OF RESTITUTION                =',E15.6,/,                 MAIN5120
     *12X,'COEFF OF FRICTION                   =',E15.6,/,                 MAIN5130
     *12X,'INITIAL KINETIC ENERGY  (IN-LB)     =',E15.6,//)                MAIN5140
 315   CONTINUE                                                            MAIN5150
      WRITE(MWRITE,309)   (TPRIM(JK),JK=1,NF)                              MAIN5160
  309 FORMAT(' THE TPRIM FOR EACH FRAGMENT IS:',3X,3D18.6 ,//)             MAIN5170
      DO 6111 I=1,NI                                                       MAIN5180
      DELDM1(I)= 0.0                                                       MAIN5190
      FLVA(I)  = 0.0                                                       MAIN5200
      FLN(I) = 0.0                                                         MAIN5210
      QACL(I)  = 0.0                                                       MAIN5220
      QCD(I)= 0.0                                                          MAIN5230
 6111 QVEL(I)= 0.0                                                         MAIN5240
       DO 37 L=1,ISIZE                                                     MAIN5250
 37    AMASS(L)=2.*AMASS(L)+DTSQ*(STIFK(L)+SPRIN(L))                       MAIN5260
       CALL FAC(AMASS,ICOL,KROW,NDEX,IDET,MWRITE,NI,NIRREG,INUM)           MAIN5270
      MIRP=0                                                               MAIN5280
      XY= TPRIM(1)/DELTAT                                                  MAIN5290
      IT= XY+0.02                                                          MAIN5300
      TIME= IT*DELTAT                                                      MAIN5310
      DO 1270 NPQ=1,NF                                                     MAIN5320
 1270 TNJ(NPQ) = 1.0                                                       MAIN5330
      IF(NF.EQ.1) GOTO 1280                                                MAIN5340
      DO 1275 NTS=2,NF                                                     MAIN5350
      IF(TPRIM(NTS).GE.0.0) GOTO 1275                                      MAIN5360
      MIRP= NTS                                                            MAIN5370
      GOTO 1280                                                            MAIN5380
 1275 CONTINUE                                                             MAIN5390
 1280 IF(MIRP.EQ.0) GOTO 1286                                              MAIN5400
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      DO 1285 NPN= MIRP,NF                                              MAIN5410
 1285 TNJ(NPN)= 0.0                                                     MAIN5420
 1286 DO 1287 I=1,NF                                                    MAIN5430
      DFCGU(I)  = UDOT(I)*DELTAT                                        MAIN5440
      DFCGW(I)  = WDOT(I)*DELTAT                                        MAIN5450
      DALFA(I)= ADOT(I)*DELTAT                                          MAIN5460
      FCGU(I)  = FCGU(I)+UDOT(I)*TPRIM(I)*TNJ(I)                        MAIN5470
      FCGW(I)= FCGW(I)+WDOT(I)*TPRIM(I)*TNJ(I)                          MAIN5480
 1287 ALFA(I)= ADOT(I)*TPRIM(I)*TNJ(I)                                  MAIN5490
      DO 1020 I=1,IKK                                                   MAIN5500
      JVEL(I)= 0                                                        MAIN5510
      EPSI(I)= 0.0                                                      MAIN5520
 1020 EPSO(I) =0.0                                                      MAIN5530
   83 FORMAT(2(I5,D20.13))                                              MAIN5540
  387 FORMAT(2I5,2D20.13)                                               MAIN5550
  386 FORMAT(3I5,2D20.13)                                               MAIN5560
   84 FORMAT(4D20.13)                                                   MAIN5570
   86 FORMAT(2I5,2D20.13,I5)                                            MAIN5580
   89 FORMAT(I5,6D12.4)                                                 MAIN5590
      WRITE(MWRITE,8255) M2,NOP                                         MAIN5600
 8255 FORMAT('0THE FOLLOWING IS THE TIME SOLUTION OF THE FRAGMENT- RING MAIN5610
     @IMPACT'      ,/,' OUTPUT WILL BE PRINTED EVERY',I5,'  CYCLES USINGMAIN5620
     @OUTPUT OPTION',I3,'.',/,' REACTION FORCES APPLIED TO THE STRUCTUREMAIN5630
     @ WILL BE PRINTED AT EACH OUTPUT CYCLE',/,' FOR NODES AT WHICH BOUNMAIN5640
     @DARY CONDITIONS ARE SPECIFIED.  D.O.F. THAT ARE',/,' NOT RESTRAINEMAIN5650
     @D AT THAT NODE WILL HAVE A REACTION FORCE = 0.0.',/,' ALL IMPACTS MAIN5660
     @WILL BE DESIGNATED AND ALL THE FRAGMENT ENERGIES WILL BE',/,' LISTMAIN5670
     @ED AFTER EACH IMPACT.')                                           MAIN5680
      NLAYP1= NLAY+1                                                    MAIN5690
      IF  (NLAYP1.GT.3)  GOTO 962                                       MAIN5700
      DO 961 I=1,IKK                                                    MAIN5710
      DO 961 J=NLAYP1, 3                                                MAIN5720
  961 H(I,J) =0.0                                                       MAIN5730
  962 CONTINUE                                                          MAIN5740
      READ(MREAD,1) ICONT                                               MAIN5750
      IF(ICONT.EQ.0) GOTO 120                                           MAIN5760
```

```
      READ(MREAD,83) IT,TIME,IMCOU,TAII                                  MAIN5770
      M=NBR+1                                                            MAIN5780
      READ(MREAD,86) (IBIGA(L),ISTAA(L),BIGA(L),BTIMA(L),ISURA(L) ,L=1,M)MAIN5790
      READ (MREAD ,386) (IBIG(L),ISURF(L),ISTA(L),BIG(L),BTIME(L),L=1,M) MAIN5800
      READ (MREAD ,387) (IBI(L),ISUR(L),BI(L),BTIM(L),L=1,M)             MAIN5810
      READ (MREAD ,89) MIRP, (TNJ(I),I=1,NF)                             MAIN5820
      READ(MREAD,84) (DISP(I),I=1,NI)                                    MAIN5830
      READ(MREAD,84) (DELD(I),I=1,NI)                                    MAIN5840
      READ(MREAD,84) (DELDM1(I),I=1,NI)                                  MAIN5850
      READ(MREAD,84) (FLVA(I),I=1,NI)                                    MAIN5860
      READ (MREAD ,84) (QVEL(I),I=1,NI)                                  MAIN5870
      READ (MREAD ,84) (QACL(I),I=1,NI)                                  MAIN5880
      READ (MREAD ,84) ((((SNS(IR,J,K,L),L=1,MNSFL),K=1,NFL),J=1,NOGA),  MAIN5890
     *IR=1,IK)                                                           MAIN5900
      READ (MREAD ,84) ((((SNP(IR,J,K,L),L=1,MNSFL),K=1,NFL),J=1,NOGA),  MAIN5910
     *IR=1,IK)                                                           MAIN5920
      READ (MREAD , 84) (FCGU(J),FCGW(J),ALFA(J),UDOT(J),WDOT(J)         MAIN5930
     *,ADOT(J),J=1,NF)                                                   MAIN5940
      WRITE(MWRITE,8265)                                                 MAIN5950
 8265 FORMAT('0THIS IS A CONTINUATION RUN')                              MAIN5960
C    START OF TIME SOLUTION                                              MAIN5970
 120    IT =IT +1                                                        MAIN5980
        TIME=IT *DELTAT                                                  MAIN5990
        IF(ICP.LE.0) GO TO 127                                           MAIN6000
        DO 128 K=1,4                                                     MAIN6010
        DISP(IK*4+K)=DISP(K)                                             MAIN6020
 128    DELD(IK*4+K)=DELD(K)                                             MAIN6030
 127    CONTINUE                                                         MAIN6040
              CALL IMPACT(EFLN,IT,NBR,QACL,QVEL,BMASS,AMASS,FLN)         MAIN6050
 45     DO 121 I=1,NI                                                    MAIN6060
      FLN(I)= FLVA(I)                                                    MAIN6070
       FLVA(I)=0.0                                                       MAIN6080
      FLVM(I) = 0.0                                                      MAIN6090
  121 CONTINUE                                                           MAIN6100
 6010 IF(MIRP.GT.NF.OR.MIRP.EQ.0) GOTO 6020                              MAIN6110
      TI=(IT*DELTAT)-(TPRIM(1)-TPRIM(MIRP))                              MAIN6120
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      IF(DABS(TI).GT.DELTAT) GOTO 6020                                  MAIN6130
      TNJ(MIRP) = 1.0                                                   MAIN6140
      MIRP= MIRP+1                                                      MAIN6150
      GOTO 6010                                                         MAIN6160
 6020 DO 822 I=1,NF                                                     MAIN6170
      FCGU(I)= FCGU(I)+DFCGU(I)*TNJ(I)                                  MAIN6180
      FCGW(I)= FCGW(I)+DFCGW(I)* TNJ(I)                                 MAIN6190
  822 ALFA(2)= ALFA(I)+ DALFA(I)* TNJ(I)                                MAIN6200
      DO 122 I=1,NI                                                     MAIN6210
      DISP(I)= DISP(I)  + DELD(I)                                       MAIN6220
  122 CONTINUE                                                          MAIN6230
             CALL STRESS(DELTAT,ASFL,GZETA,SNS,SNP,NV1,NV2,NV3)         MAIN6240
      IF(IMCO.EQ.0) GOTO 333                                            MAIN6250
      IMCO=0                                                            MAIN6260
      DO 6301 I=1,NF                                                    MAIN6270
      TRANEN(I)= FMASS(I)/2.0*(UDOT(I)**2+WDOT(I)**2)                   MAIN6280
      ROTEN(I)= FMOI(I)/2.0* ADOT(I)**2                                 MAIN6290
      CINETF(I)= TRANEN(I) + ROTEN(I)                                   MAIN6300
 6301 CONTINUE                                                          MAIN6310
      WRITE(MWRITE,6302) (I,TRANEN(I),ROTEN(I),CINETF(I),I=1,NF)        MAIN6320
 6302 FORMAT(' ',2('FRAG',I2,'  TE=',D12.4,'  RE=',D12.4,'  TOE=',      MAIN6330
     @D12.4,4X))                                                        MAIN6340
      DO 332 J=1,IKK                                                    MAIN6350
      QVEL(J*4-3)= 2.0*DELD(J*4-3)/DELTAT-QVEL(J*4-3)                   MAIN6360
      QVEL(J*4-2)= 2.0*DELD(J*4-2)/DELTAT-QVEL(J*4-2)                   MAIN6370
      QVEL(J*4)= (3.0*DELD(J*4)-DELDM1(J*4))/ (2.0*DELTAT)              MAIN6380
      QVEL(J*4-1)=(3.0*DELD(J*4-1)-DELDM1(J*4-1))/(2.0*DELTAT)          MAIN6390
  332 CONTINUE                                                          MAIN6400
      GOTO 356                                                          MAIN6410
  333 CONTINUE                                                          MAIN6420
      DO  355 I=1,NI                                                    MAIN6430
      QVEL(I)= (3.0*DELD(I)-DELDM1(I))/(2.0*DELTAT)                     MAIN6440
  355 CONTINUE                                                          MAIN6450
  356 CONTINUE                                                          MAIN6460
      DO  340 I=1,NI                                                    MAIN6470
      DELDM1(I)  = DELD(I)                                              MAIN6480
```

```
      DISUM(I)= 2.0*(DISP(I)+DELTAT*QVEL(I))                          MAIN6490
      DIS(I)= DISP(I)                                                 MAIN6500
  340 CONTINUE                                                        MAIN6510
      CALL OMULT(BMASS,DISUM,ICOL,NI,FLVM,KROW,NDEX,NIRREG)           MAIN6520
      DO 341 I=1,NI                                                   MAIN6530
      FLVM(I)=  -(2.0*FLVA(I)-FLN(I)) *DTSQ+FLVM(I)                   MAIN6540
  341 CONTINUE                                                        MAIN6550
       IF(NBCOND .EQ. 0) GO TO 124                                    MAIN6560
       DO 125 I=1,NBCOND                                              MAIN6570
       JT4=NODEB(I)*4                                                 MAIN6580
       FLVM(JT4-3)=0.0                                                MAIN6590
       IF(NBC(I).EQ.1 .OR. NBC(I).EQ.2) FLVM(JT4-1)=0.0               MAIN6600
       IF(NBC(I).EQ.2 .OR. NBC(I).EQ.3) FLVM(JT4-2)=0.0               MAIN6610
 125   CONTINUE                                                       MAIN6620
  124      CALL SOLV(AMASS,FLVM,DIS,ICOL,KROW,NDEX,NI,NIRREG)         MAIN6630
      DO 430 I=1,NI                                                   MAIN6640
      DELD(I)= DIS(I)-DISP(I)                                         MAIN6650
      QACL(I) = 2.0D+00 *(DELD(I)-DELTAT*QVEL(I))                     MAIN6660
      QCD(I)= (DELD(I)-DELDM1(I))/DTSQ                                MAIN6670
  430 CONTINUE                                                        MAIN6680
      DO 6701 I=1,IKK                                                 MAIN6690
      ITHR(I) = 0                                                     MAIN6700
      EPSI(I) = 0.0                                                   MAIN6710
 6701 EPSO(I) = 0.0                                                   MAIN6720
      MIZ=0                                                           MAIN6730
      NPZ= IT-NPZ1                                                    MAIN6740
      IF(NPZ.NE.0) GOTO 6700                                          MAIN6750
      MIZ= 1                                                          MAIN6760
      NPZ1 = NPZ1+M2                                                  MAIN6770
      IF(LGSP.EQ.0) GOTO 6700                                         MAIN6780
      WRITE(MWRITE,11100)                                             MAIN6790
      WRITE (MWRITE,6705) IT                                          MAIN6800
 6705 FORMAT('0 CYCLE=' , I8)                                         MAIN6810
      WRITE (MWRITE,6707)                                             MAIN6820
 6707 FORMAT(' ELEMENT',9X,'SI',4X,'STA 1',4X,'SO',21X,'SI',4X,'STA 2',MAIN6830
     * 4X,'SO',21X,'SI',4X,'STA 3', 4X,'SO')                          MAIN6840
```


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C   GAUSSIAN STATION STRAIN CALCULATION                                 MAIN6850
 6700 DO 7161 IR=1,IK                                                   MAIN6860
      K1= NVEC(IR, 1)                                                   MAIN6870
      K2= NVEC(IR,2)                                                    MAIN6880
      LSS= MKE(IR)                                                      MAIN6890
      DO 8018 K=1,8                                                     MAIN6900
      INDEX= (K1-1)*4+K                                                 MAIN6910
      IF(K.GT.4) INDEX= (K2-1)*4+K-4                                    MAIN6920
      DISM(K) = DISP(INDEX)                                             MAIN6930
 8018 CONTINUE                                                          MAIN6940
      IF(YK(IR).EQ.0.0) GOTO 901                                        MAIN6950
           CALL ROTAT(1,DUMMY,DISM,IR)                                  MAIN6960
  901 CONTINUE                                                          MAIN6970
      DO 604 I=1,NOGA                                                   MAIN6980
      DO 604 J=1,3                                                      MAIN6990
      BEPS (I,J)= 0.0                                                   MAIN7000
      DO 604 K=1,8                                                      MAIN7010
  604 BEPS(I,J)=BEPS(I,J)+BEP(IR,I,J,K)* DISM(K)                        MAIN7020
      NLAP= NLAY                                                        MAIN7030
      IF(MKE(IR).GT.1) NLAP =1                                          MAIN7040
      H1= H(K1,1)                                                       MAIN7050
      H2 = H(K2,1)                                                      MAIN7060
      N=MKE(IR)-1                                                       MAIN7070
      IF(YK(IR).EQ.1.0.AND.ROT(N,1).EQ.1.0) H(K1,1)= HTH(N)             MAIN7080
      IF(YK(IR).EQ.1.0.AND.ROT(N,1).EQ.0.0) H(K2,1)= HTH(N)             MAIN7090
      DO 8908 LM= 1,NLAP                                                MAIN7100
 8908 HDIF(LM) = H(K2,LM)- H(K1,LM)                                     MAIN7110
      DO 60 M=1,NOGA                                                    MAIN7120
      HINN=0.0                                                          MAIN7130
      HOUT = 0.0                                                        MAIN7140
      IF(NLAY.EQ.1) GOTO 8931                                           MAIN7150
      IF(IREF-2) 8935,8936,8937                                         MAIN7160
 8935 HL1= (H(K1,1)+HDIF(1)*AXG(M))/2.0                                 MAIN7170
      HL2= HL1+H(K1,2)+HDIF(2)*AXG(M)                                   MAIN7180
      GOTO 8938                                                         MAIN7190
 8936 HL1= -(H(K1,2)+HDIF(2)*AXG(M))/2.0                                MAIN7200
```

```
      HL2= -HL1
      IF(NLAP.EQ.2) HL2=0.0
      GOTO 8938
 8937 HL2=-(H(K1,3) +HDIF(3) * AXG(M)) /2.0
      HL1= HL2-(H(K1,2) +HDIF (2) *AXG (M))
 8938 CONTINUE
      DO 8909 LM= 1,LREF
      DIVI= 1.0
      IF(LM.EQ.LREF) DIVI=2.0
      HINN= HINN+ (H(K1,LM) + HDIF(LM) *AXG(M)) / DIVI
 8909 CONTINUE
      DO 8911 LM= LREF,NLAP
      DIVI= 1.0
      IF(LM.EQ.LREF) DIVI=2.0
      HOUT= HOUT+ (H(K1,LM) + HDIF(LM)*   AXG(M )) / DIVI
 8911 CONTINUE
      GOTO 8932
 8931 HINN= (H(K1,1)+ HDIF(1)*AXG(M)) /2.0
      HOUT = HINN
      HL1= 0.0
      HL2= 0.0
 8932 CONTINUE
      FARE= BEPS(M,1)+BEPS(M,2) **2/2.0
     * +BEPS(M,1) **2/2.
      IF(NTERF.EQ.0) GOTO 8939
      IF(NLAP.EQ.1) GOTO 8939
C   FOR MEMBRANE SET HL1 AND HL2 =0.0
      EPL1(M) = FARE+HL1*BEPS(M,3)
      EPL2(M) = FARE+HL2*BEPS(M,3)
      IF(NLAP.EQ.2) EPL2(M) = 0.0
      IF(EPL1(M) .LE.BIGL) GOTO 8940
      BIGL= EPL1(M)
      IBIGL= IR
      ISTAL= M
      ISURFL=1
      BTIMEL= TIME
```


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```
 8940 IF(NLAY.EQ.2) GOTO 8939
      IF(EPL2(M).LE.BIGL) GOTO 8939
      BIGL= EPL2(M)
      IBIGL= IR
      ISTAL= M
      ISURFL=2
      BTIMEL= TIME
 8939 CONTINUE
C   FOR MEMBRANE SET HINN AND HOUT =0.0
      EPI(M)= FARE- HINN*BEPS(M,3)
      EPO(M) = FARE+HOUT*BEPS(M,3)
      IF(EPI(M).LE.BIG(LSS)) GO TO 591
      BIG(LSS) = EPI(M)
      IBIG(LSS)= IR
      ISTA(LSS) = M
      ISURF(LSS) = 1
      BTIME(LSS) = TIME
  591 IF(EPO(M).LE.BIG(LSS)) GO TO 1200
      BIG(LSS) = EPO(M)
      IBIG(LSS)= IR
      ISTA(LSS) = M
      ISURF(LSS) = 2
      BTIME(LSS) = TIME
 1200 CONTINUE
 60     CONTINUE
C   AVERAGE NODAL STRAIN CALCULATION
C   AT A  NODE WHERE A BRANCH ATTACHES TO THE MAIN STRUCTURE,
C     THE BRANCH'S NODAL STRAIN IS NOT AVERAGED IN
      DO 6604 I=1,2
      DO 6604 J=1,3
      BEPS( I,J) = 0.0
      DO 6604 K=1,8
 6604 BEPS(I,J) = BEPS(I,J)  +DEP(IR,I,J,K)* DISM(K)
      FAR1 =BEPS(1,1)+BEPS(1,2)**2/2.0 +BEPS(1,1)**2/2.0
      FAR2 =BEPS(2,1)+BEPS(2,2)**2/2.0 +BEPS(2,1)**2/2.0
      NKE = MKE(IR)
```

```
      NLAP = NLAY
      IF(NKE.GT.1) NLAP=1
      IF(NLAP.EQ.1) GOTO 6631
      THI1= 0.0
      THO1= 0.0
      THI2= 0.0
      THO2=0.0
      DO 6619 L=1,LREF
      DIVI= 1.0
      IF(L.EQ.LREF) DIVI=2.0
      THI1= THI1 + H(K1,L)/DIVI
 6619 THI2= THI2+ H(K2,L)/DIVI
      DO 6620 L= LREF,NLAP
      DIVI=1.0
      IF(L.EQ.LREF) DIVI= 2.0
      THO1= THO1+ H(K1,L)/DIVI
 6620 THO2= THO2+ H(K2,L) /DIVI
      GOTO 6622
 6631 THI1= H(K1,1)/2.0
      THI2= H(K2,1)/2.0
      THO1= THI1
      THO2= THI2
 6622 CONTINUE
      IF(NKE.EQ.1) GOTO 6605
      IF(MATT(NKE-1).EQ.K1) GOTO 6606
 6605 ADEN = 1.0
      IF(ITHR(K1).GT.0)  ADEN=2.0
      ITHR(K1) = 1
C   FOR MEMBRANE SET THI1,THO1,THI2,THO2=0.0
      EPSI(K1)=(EPSI(K1) + FAR1- THI1*BEPS(1,3)/2.0)  /ADEN
      EPSO(K1) =(EPSO(K1) + FAR1+ THO1*BEPS(1,3)/2.0)  /ADEN
      IF(NKE.EQ.1) GOTO 6606
      IF(MATT(NKE-1).EQ.K2)  GOTO 6607
 6606 ADEN = 1.0
      IF(ITHR(K2).GT.0)  ADEN=2.0
      ITHR(K2) = 1
```


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      EPSI(K2) =(EPSI(K2) + FAR2-  THI2*BEPS(2,3)/2.0) /ADEN
      EPSO(K2)=(EPSO(K2)  + FAR2+ THO2 * BEPS(2,3)/2.0 ) /ADEN
 6607 CONTINUE
      H(K1,1)  = H1
      H(K2,1)  = H2
      IF (MIZ.NE.1) GO TO 7161
      IF(LGSP.EQ.0)  GO TO 7161
 7940 WRITE(MWRITE,6710) IR,(EPI(L),EPO(L),L=1,3)
 6710 FORMAT(' ',I3,2X,3(3X,D15.8,3X,D15.8,3X))
      IF(NLAP.EQ.1) GOTO 7161
      IF(NTERF.EQ.0) GOTO 7161
      WRITE(MWRITE,6609)  (EPL1(L),EPL2(L),L=1,3)
 6609 FORMAT(' ',5X,3(3X,D15.8,3X,D15.8,3X))
 7161  CONTINUE
C    FIND LARGEST AVERAGE NODAL STRAIN
      DO 7170 I= 1,IKK
      N= 0
      DO 7171 IR=1,IK
      IF(NVEC(IR,1).NE.I) GOTO 7172
      IF(MKE(IR).EQ.1)  N= N+1
      IF(MKE(IR).GT.1)    N= N+3
      IF(MKE(IR).GT.1)  NKE=MKE(IR)
 7172 CONTINUE
      IF(NVEC(IR,2).NE.I) GOTO 7171
      IF(MKE(IR).EQ.1)  N=N+1
      IF(MKE(IR).GT.1)    N=  N+3
      IF(MKE(IR).GT.1)    NKE= MKE(IR)
 7171 CONTINUE
      NK=1
      IF(N.EQ.3.OR.N.EQ.6) NK=NKE
      IF(EPSI(I).LE.BI(NK))  GOTO 7174
      BI(NK) = EPSI(I)
      IBI(NK)  = I
      ISUR(NK)  = 1
      BTIM(NK)  = TIME
 7174 IF(EPSO(I).LE.BI(NK))  GOTO 7170
```

```
      BI(NK) = EPSO(I)
      IBI(NK) = I
      ISUR(NK) = 2
      BTIM(NK) = TIME
 7170 CONTINUE
 7180 CONTINUE
      IF(LSPP.EQ.0) GOTO 8562
      IF(MIZ.NE.1) GOTO 8700
      WRITE(MWRITE,6705) IT
      WRITE(MWRITE,8707)
 8707 FORMAT(' STRAIN AT ADDITIONAL POINTS',10X,'SI',18X,'SO',23X,'EI',
     @18X,'EO')
 8700 DO 8761 IR= 1,IK
      IF(LKK(IR,1).EQ.0) GOTO 8761
      NLAP= NLAY
      IF(MKE(IR).GT.1) NLAP =1
      K1 = NVEC(IR,1)
      K2= NVEC(IR,2)
      DO 8019 K=1,8
      INDEX= (K1-1)*4+K
      IF(K.GT.4) INDEX= (K2-1)*4+K-4
      DISM(K) = DISP(INDEX)
 8019 CONTINUE
      IF(YK(IR).EQ.0.0) GOTO 902
           CALL ROTAT(1,DUMMY,DISM,IR)
  902 CONTINUE
      H1= H(K1,1)
      H2 = H(K2,1)
      L= MKE(IR)
      N=MKE(IR)-1
      IF(YK(IR).EQ.1.0.AND.ROT(N,1).EQ.1.0) H(K1,1)= HTH(N)
      IF(YK(IR).EQ.1.0.AND.ROT(N,1).EQ.0.0) H(K2,1)= HTH(N)
      NO= LKK(IR,1)
      DO 8763 I= 1,NO
      IS = LKK(IR,I+1)
      DO 8604 J=1,3
```


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      AEPS(J) = 0.0
      DO 8604 K= 1,8
 8604 AEPS(J)=AEPS(J) + AEP(IS,J,K)*DISM(K)
      DO 8918 LM= 1,NLAP
 8918 HDIF(LM) = H(K2,LM)- H(K1,LM)
      HINN=0.0
      HOUT = 0.0
      IF(NLAP.EQ.1) GOTO 8941
      IF(LREF-2) 8735,8736,8737
 8735 HL1= (H(K1,1)+HDIF(1)*AXG(M))/2.0
      HL2= HL1+ H(K1,2)+HDIF(2)*AXG(M)
      GOTO 8738
 8736 HL1= -(H(K1,2)+HDIF(2)*AXG(M))/2.0
      HL2= -HL1
      IF(NLAP.EQ.2) HL2= 0.0
      GOTO 8738
 8737 HL2= -(H(K1,3)+HDIF(3)*AXG(M))/2.0
      HL1= HL2-(H(K1,2)+HDIF(2)*AXG(M))
 8738 CONTINUE
      DO 8919 LM= 1,LREF
      DIVI= 1.0
      IF(LM.EQ.LREF) DIVI=2.0
      HINN= HINN+ (H(K1,LM)+ HDIF(LM)*AZET(IS))/ DIVI
 8919 CONTINUE
      DO 8921 LM= LREF,NLAP
      DIVI= 1.0
      IF(LM.EQ.LREF) DIVI=2.0
      HOUT= HOUT+ (H(K1,LM)+ HDIF(LM)*  AZET(IS)) / DIVI
 8921 CONTINUE
      GOTO 8942
 8941 HINN= (H(K1,1)+HDIF(1)*AZET(IS))/ 2.0
      HOUT = HINN
      HL1= 0.0
      HL2= 0.0
 8942 CONTINUE
      FARE= AEPS(1)+AEPS(2)**2/2.0+AEPS(1)**2/2.0
```

```
      IF (NTERF.EQ.0) GOTO 8739
      IF(NLAP.EQ.1) GOTO 8739
C    THIS IS A CALCULATION OF THE STRAINS AT THE INTERFACES
C    FOR MEMBRANE SET HL1 AND HL2 =0.0
      EPAS1= FARE+HL1* AEPS (3)
      EPAS2= FARE+HL2*AEPS(3)
      IF (NLAP.EQ.2)  EPAS2= 0.0
      IF (EPAS1.LE.BIGAL) GOTO 8740
      BIGAL= EPAS1
      IBIGAL= IR
      ISTAAL= IS
      BTIMAL= TIME
      ISURAL= 1
 8740 IF (NLAY.EQ.2) GOTO  8739
      IF(EPAS2.LE.BIGAL) GOTO 8739
      BIGAL= EPAS2
      IBIGAL= IR
      ISTAAL= IS
      BTIMAL= TIME
      ISURAL = 2
 8739 CONTINUE
C    FOR MEMBRANE SET HINN AND HOUT =0.0
      EPASI = FARE- HINN*AEPS(3)
      EPASO = FARE+ HOUT*AEPS(3)
C    FIND LARGEST ADDTIONAL POINT STRAIN
      IF(EPASI.LE.BIGA(L))   GO TO 8591
      BIGA(L)  = EPASI
      IBIGA(L) = IR
      ISTAA(L) = IS
      BTIMA(L) = TIME
      ISURA(L) = 1
 8591 IF(EPASO.LE.BIGA(L)) GO TO 8780
      BIGA(L)  = EPASO
      IBIGA(L) = IR
      ISTAA(L) = IS
      BTIMA(L) = TIME
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      ISURA(L) = 2
 8780 IF(MIZ.NE.1) GO TO 8763
      EI= DSQRT(1.0+2.0* EPASI) -1.0
      EO= DSQRT(1.0+2.0* EPASO) -1.0
      WRITE(MWRITE,8781) IS,EPASI,EPASO,EI,EO
 8781 FORMAT(' ',10X,I3,16X,D15.8,4X,D15.8,11X,D15.8,4X,D15.8)
      IF(NLAP.EQ.1) GOTO 8763
      IF(NTERF.EQ.0) GOTO 8763
      WRITE(MWRITE,8609) EPAS1,EPAS2
 8609 FORMAT(' ',29X,D15.8,4X,D15.8)
 8763 CONTINUE
      H(K1,1) = H1
      H(K2,1) = H2
 8761 CONTINUE
 8562 CONTINUE
       IF(IT-M1) 131,140,150
 140   M1=M1+M2
       CALL PRINT(IT,TIME,HINN,HOUT,APDEN,SPRIN,BMASS,C2,NQR,CINETO,
     *BEP,WET,NV,ES,ASFL,SNS,NV1,NV2,NV3,SOL,QVEL)
      IF(NBCOND.EQ.0) GOTO 260
      DO 276 I=1,NI
      REAFK(I)=0.0
  276 CONTINUE
         CALL OMULT(REACK,DISP,ICOL,NI,REAFK,KROW,NDEX,NIRREG)
      DO 261 I=1,21
  261 REAC(I)=0.0
      DO 262 I=1,NBCOND
      J= NODEB(I)*4
      K= (I-1)*3
      REAC(K+1) = REAFK(J-3)+FLVA(J-3)
      IF(NBC(I).EQ.1.OR.NBC(I).EQ.2) REAC(K+3)=REAFK(J-1)+FLVA(J-1)
      IF(NBC(I).EQ.2.OR.NBC(I).EQ.3) REAC(K+2)=REAFK(J-2)+FLVA(J-2)
  262 CONTINUE
      WRITE(MWRITE,256)
  256 FORMAT('0',6X,'REACTIONS AT NODE',15X,'RV(LBS)',13X,'RW(LBS)',
     @11X,'RM(IN-LBS)')
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```
      DO 252 I=1,NBCOND
      J= (I-1) *3
      WRITE(MWRITE,253) NODEB(I),REAC(J+1),REAC(J+2),REAC(J+3)
  253 FORMAT(' ',18X,I4,5X,3D20.6)
  252 CONTINUE
  260 CONTINUE
      M=NBR+1
      WRITE(MWRITE,66)
      WRITE(MWRITE,67) (L,BIG(L),IBIG(L),ISURF(L),ISTA(L),BTIME(L),L=1,M)
      IF(NTERF.EQ.0) GOTO 1272
      WRITE(MWRITE, 59) BIGL,IBIGL,ISURFL,ISTAL,BTIMEL
   59 FORMAT(' INTERFACE',4X,D15.6,1X,I4,4X,I4,4X,I4,4X,D15.6)
 1272 CONTINUE
      IF(LSPP.NE.1) GO TO 8782
      WRITE(MWRITE,6030)
      WRITE(MWRITE,6035) (L,BIGA(L),IBIGA(L),ISTAA(L),BTIMA(L),ISURA(L),
     @L=1,M)
      IF(NTERF.EQ.0) GOTO 1273
      WRITE(MWRITE,1271) BIGAL,IBIGAL,ISTAAL,BTIMAL,ISURAL
 1271 FORMAT(' INTERFACE',14X,D15.6,7X,I3,6X,I5,5X,D15.6,6X,I4)
 1273 CONTINUE
 8782 CONTINUE
      WRITE(MWRITE,7181)
      WRITE(MWRITE,7182) (L,BI(L),IBI(L),ISUR(L),BTIM(L),L=1,M)
 7181 FORMAT('0SUBSTRUCTURE',5X,'LARGEST  NODAL  STRAIN ',5X,'NODE',7X,
     @'SURF',11X,'TIME')
 7182 FORMAT(' ',4X,I3,16X,D15.6,7X,I3,6X,I5,5X,D15.6)
      WRITE(MWRITE,11100)
11100 FORMAT('0*****************************************************
     @***********************************************************
     @*********',/)
  131  IF(IT-MM) 120,170,150
  170 CONTINUE
      WRITE(MWRITE,6002)
 6002 FORMAT('OTHE LARGEST COMPUTED STRAINS FOR EACH SUBSTRUCTURE--
     @MAIN AND BRANCHES -- ARE PRINTED BELOW,  1= INNER  2= OUTER SURF')
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      M= NBR+1
      WRITE(MWRITE,66)
      WRITE(MWRITE,67) (L,BIG(L),IBIG(L),ISURF(L),ISTA(L),BTIME(L),L=1,M)
   66 FORMAT('OSUBSTRUCTURE',8X,'MSTR',7X,'ELE',5X,'SURF',5X,'STA',
     @9X,'TIME')
   67 FORMAT(' ',3X,I4,6X,D15.6,1X,I4,4X,I4,4X,I4,4X,D15.6)
      IF(NTERF.EQ.0) GOTO 1274
      WRITE(MWRITE, 59) BIGL,IBIGL,ISURFL,ISTAL,BTIMEL
 1274 CONTINUE
      IF(LSPP.NE.1) GOTO 149
      WRITE(MWRITE,6030)
      WRITE(MWRITE,6035) (L,BIGA(L),IBIGA(L),ISTAA(L),BTIMA(L),ISURA(L),
     @L=1,M)
 6030 FORMAT('OSUBSTRUCTURE',5X,'LARGEST ADD. PT. STRAIN',5X,'ELEM',5X,
     @'ADD. PT.',9X,'TIME',10X,'SURFACE')
 6035 FORMAT(' ',4X,I3,16X,D15.6,7X,I3,6X,I5,5X,D15.6,6X,I4)
      IF(NTERF.EQ.0) GOTO 149
      WRITE(MWRITE,1271) BIGAL,IBIGAL,ISTAAL,BTIMAL,ISURAL
  149 CONTINUE
      WRITE(MWRITE,7181)
      WRITE(MWRITE,7182) (L,BI(L),IBI(L),ISUR(L),BTIM(L),L=1,M)
  150 IF(MPU.EQ.0) GOTO 160
      WRITE( MPUNCH,83) IT,TIME,IMCOU,TAII
      M= NBR+1
      WRITE(MPUNCH,86) (IBIGA(L),ISTAA(L),BIGA(L),BTIMA(L),ISURA(L),
     @L=1,M)
      WRITE(MPUNCH,386) (IBIG(L),ISURF(L),ISTA(L),BIG(L),BTIME(L),L=1,M)
      WRITE(MPUNCH,387) (IBI(L),ISUR(L),BI(L), BTIM(L),L=1,M)
      WRITE(MPUNCH,89) MIRP, (TNJ(I),I=1,NF)
      WRITE(MPUNCH,84) (DISP(I),I=1,NI)
      WRITE(MPUNCH,84) (DELD(I),I=1,NI)
      WRITE(MPUNCH,84) (DELDM1(I),I=1,NI)
      WRITE(MPUNCH,84) (FLVA(I),I=1,NI)
      WRITE(MPUNCH,84) (QVEL(I),I=1,NI)
      WRITE(MPUNCH,84) (QACL(I),I=1,NI)
      WRITE(MPUNCH,84) ((((SNS(IR,J,K,L),L=1,MNSFL),K=1,NFL),J=1,NOGA),
```

```
     *IR=1,IK)
      WRITE(MPUNCH,84) ((((SNP(IR,J,K,L),L=1,MNSFL),K=1,NFL),J=1,NOGA),
     *IR=1,IK)
      WRITE(MPUNCH, 84)  (FCGU(J),FCGW(J),ALFA(J),UDOT(J),WDOT(J)
     *,ADOT(J),J=1,NF)
      WRITE(MWRITE,6005)
 6005 FORMAT('OCONTINUATION CARDS HAVE BEEN PUNCHED FOR THIS RUN')
      GO TO 161
  160 WRITE(MWRITE,6036)
 6036 FORMAT('ONO CARDS PUNCHED DURING THIS RUN FOR CONTINUATION.')
  161 IF(ICON.EQ.0) GOTO 151
      IRRUN = IRRUN +1
      GO TO 5555
  151 CALL EXIT
      END

      SUBROUTINE IMPACT(EFLN,IT,NBR,QACL,QVEL,BMASS,AMASS,FLN)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION DISM(205),DISUM(205),FLVM(205),BMASS(1),AMASS(1),FLN(1)
      DIMENSION PD(50,6),PALE(50,6)
      DIMENSION  QACL(205)   , QVEL(205)
      DIMENSION AY(51),AZ(51)
      DIMENSION TU(205), TW(205)
      DIMENSION VY(51),VZ(51),TFCGU(6),TFCGW(6),TALFA(6),IFLAG(51,6),
     2NTSD(6),NEF(6),RL(50),EFLN(6)
      DIMENSION AYCD(51), AZCD(51)
      COMMON /HIT/ TNJ(6), MIRP
      COMMON /ACC/ QCD(205)
      COMMON/IMPI/ VEL(102),IMCO,JVEL(51)
      COMMON/TAPE/MREAD,MWRITE,MPUNCH
      COMMON/FC/ Y(51),Z(51),ANG(51),H(51,3)
      COMMON /VQ/ FLVA(205),DISP(205),DELD(205),BINP(50,3),BIMP(50,3)
      COMMON /FRAGV/ VELFU(3),VELFW(3),VELFA(3)
      COMMON/FRAG/ FH(3),FMASS(3),FMOI(3),UNK(3),CR(3),FCGU(3),FCGW(3),
     @ALFA(3),DFCGU(3),DFCGW(3),DALFA(3),TREL,FKT(3),DELTAT,NF,MIMP
      COMMON/FG/ IK,IKK,ICP,LREF,NOGA,NFL,NI,ICOL(205),INUM(205)
     @,NBCOND,NBC(7),NODEB(7),KROW(8),NDEX(8),NIRREG
      COMMON/BR/ NVEC(51,2), LMT(51)
      COMMON/LEFT/RMASS(51)
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      COMMON/IIAT/ TAII, IMCOU                                          IMPA0240
      COS(ZZZ)=DCOS(ZZZ)                                                IMPA0250
      SIN(ZZZ)=DSIN(ZZZ)                                                IMPA0260
C   ***********************************************                     IMPA0270
C                                                                       IMPA0280
C **** MODIFIED IMPACT CONTROLLING ROUTINE  *********                   IMPA0290
C                                                                       IMPA0300
C   CURRENT TIME REMAINING IN THIS TIME STEP=EXTERNAL TIME STEP         IMPA0310
C   AND CURRENT TIME = TB.                                              IMPA0320
      TIMEI=(IT-1)*DELTAT                                               IMPA0330
      TIMEF = IT*DELTAT                                                 IMPA0340
      DELTR=DELTAT                                                      IMPA0350
      TB=TIMEI                                                          IMPA0360
      JF=1                                                              IMPA0370
 8100 FORMAT(' VZ=',10D12.4)                                            IMPA0380
 8110 FORMAT(' TW=',10D12.4)                                            IMPA0390
 8120 FORMAT(' TFCGW=',D15.6,'  VELFW=',D15.6)                          IMPA0400
 8130 FORMAT(' DISM=',10D12.4)                                          IMPA0410
 8140 FORMAT(' FLVM86=',D15.6,'   FLVM90=',D15.6)                       IMPA0420
C                                                                       IMPA0430
C   INITIALIZE CORRECTION 'FLAGS' TO NO-PREV.-CORR. POSITION (=0),     IMPA0440
C   AND NO. OF SUBDIVISIONS FOR EACH FRAG. TO ZERO                     IMPA0450
      DO 5 I=1,IK                                                       IMPA0460
      DO 5 J=1,NF                                                       IMPA0470
      NTSD(J)=0                                                         IMPA0480
 5    IFLAG(I,J)=0                                                      IMPA0490
C                                                                       IMPA0500
C   TRANSFORM NODAL VELOCITIES INTO Y AND Z COMPONENTS                 IMPA0510
C                                                                       IMPA0520
C   CALC. TRIAL POSITION OF RING NODES AND FRAGMENT TO THE END OF THIS IMPA0530
C   INTERNAL TIME STEP                                                  IMPA0540
      DO 7000 I=1,NI                                                    IMPA0550
 7000 DISM(I)= DISP(I) + DELD(I)                                        IMPA0560
C                                                                       IMPA0570
C   TRIAL POSITION OF FRAGMENT                                          IMPA0580
C                                                                       IMPA0590
```

```
C    RETURN POSITION FOR SUBSEQUENT INSPECTION AFTER INITIAL PENETRATION IMPA0600
C    CORRECTION.                                                        IMPA0610
      NEQ=0                                                             IMPA0620
 20   CONTINUE                                                          IMPA0630
C                                                                       IMPA0640
      DO 7035 I=1,NF                                                    IMPA0650
      TFCGU(I)= FCGU(I)+VELFU(I)*DELTR*TNJ(I)                           IMPA0660
      TFCGW(I)= FCGW(I)+VELFW(I)*DELTR*TNJ(I)                           IMPA0670
 7035 TALFA(I)= ALFA(I)+ VELFA(I)*DELTR*TNJ(I)                          IMPA0680
    6 DO 10 I=1,IKK                                                     IMPA0690
      VY(I)= QVEL(I*4-3)*COS(ANG(I))-QVEL(I*4-2)*SIN(ANG(I))            IMPA0700
   10 VZ(I)=  QVEL(I*4-3)*SIN(ANG(I))+QVEL(I*4-2)*COS(ANG(I))           IMPA0710
      DO 7025 I=1,IKK                                                   IMPA0720
      TU(I)=Y(I)+DISM(I*4-3)*COS(ANG(I))-DISM(I*4-2)*SIN(ANG(I))        IMPA0730
      TW(I)=Z(I)+DISM(I*4-3)*SIN(ANG(I))+DISM(I*4-2)*COS(ANG(I))        IMPA0740
 7025 CONTINUE                                                          IMPA0750
      IF(NTSD(JF).GT.5 )  GOTO 150                                      IMPA0760
      IF(NEQ.EQ.0) GOTO 7200                                            IMPA0770
      NEQ=NEQ-1                                                         IMPA0780
      PD(IBIG,JF)= -1.0                                                 IMPA0790
      DO 7210 IR=1,IK                                                   IMPA0800
      DO 7210 J=1,NF                                                    IMPA0810
      IF(PD(IR,J)-PMAX) 7210,7220,7220                                  IMPA0820
 7210 CONTINUE                                                          IMPA0830
      GOTO 7200                                                         IMPA0840
 7220 PAL= PALE(IR,J)/RL(IR)                                            IMPA0850
      IBIG=IR                                                           IMPA0860
      JF=J                                                              IMPA0870
      GOTO 7290                                                         IMPA0880
 7200 CONTINUE                                                          IMPA0890
C                                                                       IMPA0900
C    CALC. PENETRATION DISTANCES FOR THIS TRIAL POSITION.               IMPA0910
      CALL PENTRN(TU,TW,TFCGU,TFCGW,NPP,PMAX,NEF,NEQ,JF,PAL,RL,IBIG,    IMPA0920
     2H,FH,IK,NF,ICP,PD,PALE)                                           IMPA0930
C                                                                       IMPA0940
C    CHECK PENETRATIONS.                                                IMPA0950
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C   IF THE NUMBER OF POSITIVE PENETRATIONS, NPP, IS ZERO, AND THE        IMPA0960
C   MAX.PENETRATION IS LESS THAN ZERO, NO (MORE) PENETRATIONS OCCUR FOR IMPA0970
C   THIS TIME STEP.                                                      IMPA0980
      IF(NPP.EQ.0.AND.PMAX.LT.0.0)GO TO 150                              IMPA0990
C                                                                        IMPA1000
C   IF MAX. PENETRATION IS ZERO, SKIP SUBDIVISION PROCESS.               IMPA1010
 7290 CONTINUE                                                           IMPA1020
      TT=TB                                                              IMPA1030
      TMIN=DELTR                                                         IMPA1040
C                                                                        IMPA1050
C   RETURN FRAGMENT AND NODAL POSITIONS TO BEGINNING OF THIS INTERNAL    IMPA1060
C   TIME STEP.                                                           IMPA1070
      DO 35 I=1,NF                                                       IMPA1080
      TFCGU(I)=FCGU(I)                                                   IMPA1090
      TFCGW(I)=FCGW(I)                                                   IMPA1100
 35   TALFA(I)=ALFA(I)                                                   IMPA1110
      DO 25 I=1,IKK                                                      IMPA1120
      TU(I)=Y(I)+DISP(I*4-3)*COS(ANG(I))-DISP(I*4-2)*SIN(ANG(I))         IMPA1130
      TW(I)=Z(I)+DISP(I*4-3)*SIN(ANG(I))+DISP(I*4-2)*COS(ANG(I))         IMPA1140
   25 CONTINUE                                                           IMPA1150
C                                                                        IMPA1160
C   CALC. TIME OF CONTACT, ELEM. AFFECTED, AND POINT OF CONTACT.         IMPA1170
C                                                                        IMPA1180
C   UPDATE NODAL AND FRAG. POSITIONS TO THIS TIME                        IMPA1190
 100  CONTINUE                                                           IMPA1200
      NTSD(JF)=NTSD(JF)+1                                                IMPA1210
      IMCOU = IMCOU+1                                                    IMPA1220
C                                                                        IMPA1230
C   UPDATE NODAL VELOCITIES (VY,VZ), AND FRAGMENT VELOCITIES (VELFU,     IMPA1240
C   VELFW, VELFA) TO POST-IMPACT VALUES.                                 IMPA1250
      WRITE(MWRITE,8000) IMCOU,TT,IT,IBIG,JF,PAL                         IMPA1260
 8000 FORMAT('0IMPACT NO.',I5,5X,'TIME',D15.6,5X,'DURING CYCLE',I5,5X,   IMPA1270
     &'ELEM',I5,5X,'FRAG',I5,5X,'DISTANCE',D15.6)                        IMPA1280
C                                                                        IMPA1290
C   TIME REMAINING IN THIS EXTERNAL TIME STEP                            IMPA1300
      IF(IMCOU.EQ.1)     TAII = TT                                       IMPA1310
```

```
      CALL IMPCTE(TU,TW,VY,VZ,VELFU,VELFW,VELFA,JF,IBIG,RMASS,
     2FMASS,FMCI,CE,UNK,PAI,EFLN,H,FH,IK,NF,ICP,RL,NBR,NBCOND,NODEB
     3,DELTR,AY,AZ,ANG,AYCD,AZCD)
      IMCO = 1
      DO 7050 I=1,IKK
      QVEL(I*4-3)  = VY(I)*COS(ANG(I))+VZ(I)*SIN(ANG(I))
      QVEL(I*4-2)= -VY(I)*SIN(ANG(I))+VZ(I)*COS(ANG(I))
 7050 CONTINUE
      DO 7340 I=1,NI
      FLVM(I)= 0.0
 7340 DISUM(I)= 2.0*(DISP(I)+DELTAT*QVEL(I))
      CALL OMULT(BMASS,DISUM,ICOL,NI,FLVM,KROW,NDEX,NIRREG)
      DTSQ= DELTAT**2
      DO 7341 I=1,NI
 7341 FLVM(I)= -(2.0*FLVA(I)-FLN(I))*DTSQ+FLVM(I)
      IF(NBCOND.EQ.0) GOTO 7124
      DO 7125 I=1,NBCOND
      JT4 = NODEB(I)*4
      FLVM(JT4-3)  = 0.0
      IF(NBC(I).EQ.1.OR.NBC(I).EQ.2)  FLVM(JT4-1)=0.0
      IF(NBC(I).EQ.2.OR. NBC(I).EQ.3)  FLVM(JT4-2)= 0.0
 7125 CONTINUE
 7124 CONTINUE
      CALL SOLV(AMASS,FLVM,DISM,ICOL,KROW,NDEX,NI,NIRREG)
C
C    CHECK FOR ADDITIONAL IMPACTS IN THIS EXTERNAL TIME STEP.
      GO TO 20
C
C    NO ADDITIONAL IMPACTS OCCUR IN THIS TIME STEP.
  150 CONTINUE
C
C    RETURN TO CONTROLLING ROUTINE WITH FINAL DISPLACEMENT INCREMENTS.
C    FRAGMENT LOCATION.
      DO 160 I=1,NF
      DFCGU(I)= TFCGU(I)-FCGU(I)
      DFCGW(I)  =  TFCGW(I)- FCGW(I)
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  160 DALFA(I)= TALFA(I) - ALFA(I)
C
C   IF NO IMPACTS HAVE OCCURED, NO FURTHER UPDATE IS REQUIRED.
      NSUM=0
      DO 165 I=1,NF
 165  NSUM=NSUM+NTSD(I)
      IF(NSUM.EQ.0) RETURN
C
C   IF IMPACT HAS OCCURED, UPDATE VELOCITIES
      DO 170 I=1,NI
 170  DELD(I)= DISM(I)-DISP(I)
      RETURN
      END

      SUBROUTINE IMPCTE(TU,TW,VU,VW,VELFU,VELFW,VELFA,JBIG,IBIG,RMASS,
     2FMASS,FMOI,CR,UNK,PAL,EFLN,H,FH,IK,NF,ICP,RL,NBR,NBCOND,NODEB
     3,DELTR,AY,AZ,ANG,AYCD,AZCD)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION NODEB(1), H(51,3)
      DIMENSION AY(1),AZ(1),ANG(1)
      DIMENSION AYCD(51), AZCD(51)
      DIMENSION TU(1),TW(1),VU(1),VW(1),VELFU(1),VELFW(1),VELFA(1),
     @FMASS(1),RMASS(1),FMOI(1),CR(1),UNK(1),EFLN(1),RL(1),FH(1)
      DIMENSION       SSL(25),GAM(25),BET(25),SSR(25)
      DIMENSION MNO(51) , MNOD(51),  LT(11),PK(11)
      DIMENSION MBC(8)     , EF(6)
      COMMON /BOUN/ YK(51),NBCONB,NBCB(7),NODBB(7),MK(51),ROT(5,2)
     @,XDIST(6),DROT(50),NODP(6)
      COMMON/IMPT/ VEL(102),IMCO,JVEL(51)
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      COMMON/BB/ NVEC(51,2), LMT(51)
      COMMON /TAM/ MKE(51)
      COMMON /ML/ MNEL(6),MATT(6)
      SIN(Q)= DSIN(Q)
      COS(Q) = DCOS(Q)
      MEF=1
```

```
      NS=IK
      IF(ICP.GT.0) NS = IK+1
      IF(NBCOND.EQ.0) NODEB(1) = 0
      DO 1000 I=1,IK
      L1= NVEC(I,1)
      L2= NVEC(I,2)
C   ESTABLISH ELEMENT LENGTH, ANGLES AND DISTANCES TO NODES
      RL(I) = DSQRT((TW(L2)-TW(L1))**2+(TU(L2)-TU(L1))**2)
 1000 CONTINUE
      JNBR=NBR+1
      DO 100 I=1,JNBR
  100 EF(I)= EFLN(I)
      L1 = NVEC(IBIG,1)
      L2 = NVEC(IBIG,2)
      RSIN= (TW(L2)-TW(L1))/RL(IBIG)
      RCOS= (TU(L2)-TU(L1)) / RL(IBIG)
      IBI= NVEC(IBIG,1)
C   PAL = DISTANCE TO NODE1  PAX = DISTANCE TO NODE2
      IF(PAL.EQ.0.0.OR.PAL.EQ.1.0)  GOTO 937
      GOTO 934
  937 LZ=L1
      IF(PAL.EQ.1.0) LZ=L2
      DO 1007 I=1,NBCOND
      IF(LZ.EQ.NODEB(I))  GOTO 1006
 1007 CONTINUE
      GOTO 934
 1006 CONTINUE
      KII=1
      BET(1) = 0.0
      MNOD(1) = NVEC(IBIG,1)
      IF(PAL .EQ.1.0) MNOD(1) = NVEC(IBIG,2)
      GOTO 936
  934 CONTINUE
      PAL= PAL *RL(IBIG)
      PAX= RL(IBIG)-PAL
 5555 CONTINUE
```


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      MBC(1) =0
      ZK=1.0
       MIMI=0
      MIMR = 0
      DO 998 I= 2,JNBR
  998 EFLN(I) = EF(I)
      MMFL = 0
       KIL=1
C     ESTABLISH THE NUMBER OF NODES  COUNTERCLOCKWISE FROM IMPACT WITHIN
       SSL(KIL)=PAL
      MEF=MKE(IBIG)
      IF(MEF.EQ.1)   GO TO 1010
      WRITE  (MWRITE,1009)
 1009 FORMAT(' IMPACT ON A BRANCH IS NOT PRESENTLY ALLOWED-- NO IMPACT')
      GO TO 350
 1010 CONTINUE
      IF(PAL.GE.EFLN(MEF)) GO TO 300
      MNO(KIL) = NVEC(IBIG, 1)
      IFF = 0
      IF2=0
      IF3 =0
       MIML=1
      DO 301 J=1,25
      GAM(KIL)= ZK-SSL(KIL-IF3)/EFLN(MEF)
      IF(MMFL.NE.1) GO TO 931
      EFLN(MEF) = 0.99*SSL(KIL-IF3)
      GO TO  5555
  931 DO 940 NC=1,NBCOND
      IF(MNO(KIL).NE.NODEB(NC)) GOTO 940
      MBC(1) = MBC(1) +1
      MBC(MBC(1)+1) = NODEB(NC)
      MMFL=1
      IF(MNO(KIL).NE.1.AND.MKE(JEL-1).EQ.1) GOTO 932
      EFLN(MEF) = SSL(KIL-IF3)
      GOTO 5555
  932 CONTINUE
```

```
      GOTO 950
  940 CONTINUE
  950 CONTINUE
      JEL = IBIG - KIL -IFF
      IF2 =0
       IF(ICP.LE.0.AND.JFL.LE.0) GO TO 302
       IF(ICP.GT.0.AND.JFL.LE.0) JEL=JEL+IK
C     CHECK FOR A BRANCH ATTACHMENT POINT
      IF(NBR.EQ.0) GO TO 1038
      DO 1020 I = 1,NBR
      IF(MNO(KIL).NE.MATT(I)) GO TO 1020
      NB = I+1
      MTI = MATT(I)
      EST = GAM(KIL)
      GO TO 1030
 1020 CONTINUE
      GO TO  1038
C     COMPUTE BRANCH NODES INVOLVED IN MOMENTUM TRANSFER,
 1030 RX = 0.0
      IF(MMFL.EQ.1) GOTO 1038
      NUMB = 0
      MBFL=0
      KL = 0
      DO 1035 I= 1,10
      IF(MBFL.NE.1) GO TO 910
      NUMB = NUMB+1
      IF(NUMB.NE.2) GOTO 910
      EFLN(NB) = 0.99* RX/EST
      GOTO 1030
  910 CONTINUE
      IF(NODP(NB-1).NE.1) GOTO 2050
      IF((MTI-1).EQ.0) GOTO 1037
      RX= RX+RL(MTI-I)
      P = EST-RX/EFLN(NB)
      IF (P.LE.0.0) GO TO 1037
      LT(KL+1) = MTI-I
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      GOTO 2060
 2050 CONTINUE
      IF (MKE(MTI+I-1).NE.NB)   GO TO 1037
      RX= RX+RL(MTI+I-1)
      P = EST-RX/EFLN(NB)
      IF (P.LE.0.0) GO TO 1037
      LT(KL+1) = MTI+I
 2060 CONTINUE
      PK(KL+1) = P
      DO 900 NC= 1,NBCOND
      IF(LT(KL+1).NE.NODEB(NC)) GOTO 900
      MBC(1) = MBC(1)+1
      MBC(MBC(1)+1) = NODEB(NC)
      MBFL=1
      GOTO 920
  900 CONTINUE
  920 CONTINUE
      KL = KL+1
 1035 CONTINUE
 1037 L = KIL+1
      IF3 = IF3 +KL
      IFF=MNEL(NB-1) -KL +IFF
      IF2 = MNEL(NB-1)
      IF (KL.EQ.0) GO TO 1038
      KIL = KIL +KL
      DO 1036 I = L,KIL
      LZ= KL -I+L
      GAM(I) = PK(LZ)
 1036 MNO (I) = LT(LZ)
 1038 CONTINUE
      JEL = JEL -IF2
      IF (JEL.EQ.0) GO TO 302
      SSL(KIL+1-IF3) = SSL(KIL-IF3) + RL(JEL)
      IF(EFLN(MEF).LE.SSL(KIL+1-IF3)) GOTO 302
      KIL = KIL +1
      MNO(KIL) = NVEC(JEL,1)
```

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  301 CONTINUE                                                            IMPT1670
  302 DO 303 JJ= 1,KIL                                                    IMPT1680
      MNOD(JJ) = MNO(KIL-JJ+1)                                            IMPT1690
  303 BET(JJ) = GAM(KIL-JJ+1)                                             IMPT1700
  300 CONTINUE                                                            IMPT1710
      IF2=0                                                               IMPT1720
      IF3 =0                                                              IMPT1730
      IFF = 0                                                             IMPT1740
      MMFL = 0                                                            IMPT1750
      KIR=1                                                               IMPT1760
C     ESTABLISH THE NUMBER OF NODES         CLOCKWISE FROM IMPACT WITHINIMPT1770
       SSR(KIR)=PAX                                                       IMPT1780
      IF(PAX           .GE.EFLN(MEF)) GO TO 304                           IMPT1790
      MNOD(KIR+KIL) = NVEC(IBIG,2)                                        IMPT1800
       MIMR=1                                                             IMPT1810
      DO 305 J = 1,25                                                     IMPT1820
      BET(KIL+KIR) = ZK-SSR(KIR-IF3) /EFLN(MEF)                           IMPT1830
      IF(MMFL.NE.1) GO TO 941                                             IMPT1840
      EFLN(MEF) = 0.99*SSR(KIR-IF3)                                       IMPT1850
      GO TO  5555                                                         IMPT1860
  941 DO 945 NC= 1,NBCOND                                                 IMPT1870
      IF(MNOD(KIL+KIR).NE.NODEB(NC)) GO TO 945                            IMPT1880
      MBC(1) = MBC(1) +1                                                  IMPT1890
      MBC(MBC(1)+1) = NODEB(NC)                                           IMPT1900
      MMFL=1                                                              IMPT1910
      IF(MNOD(KIL+KIR).NE.NS.AND.MKE(JEL+1).EQ.1)GOTO 933                 IMPT1920
      EFLN(MEF) = SSR(KIR-IF3)                                            IMPT1930
      GOTO 5555                                                           IMPT1940
  933 CONTINUE                                                            IMPT1950
      GOTO 955                                                            IMPT1960
  945 CONTINUE                                                            IMPT1970
  955 CONTINUE                                                            IMPT1980
      JER= IBIG+KIR+IFF                                                   IMPT1990
      IF2=0                                                               IMPT2000
       IF(ICP.LE.0.AND.JER.GT.IK) GO TO 306                               IMPT2010
       IF(ICP.GT.0.AND.JER.GT.IK) JER=JER-IK                              IMPT2020
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C     CHECK FOR A BRANCH ATTACHMENT POINT                                IMPT2030
      IF(NBR.EQ.0) GO TO 1080                                            IMPT2040
      DO 1050 I = 1,NBR                                                  IMPT2050
      IF (MNOD(KIL+KIR) .NE.MATT(I)) GO TO 1050                          IMPT2060
      NB= I+1                                                            IMPT2070
      MTI = MATT(I)                                                      IMPT2080
      EST = BET(KIL+KIR)                                                 IMPT2090
      GO TO 1060                                                         IMPT2100
 1050 CONTINUE                                                           IMPT2110
      GO TO 1080                                                         IMPT2120
C     COMPUTE BRANCH NODES INVOLVED IN MOMENTUM TRANSFER,                IMPT2130
 1060 RX =0                                                              IMPT2140
      MBFL=0                                                             IMPT2150
      NUMB = 0                                                           IMPT2160
      KL =0                                                              IMPT2170
      DO 1055 I = 1,10                                                   IMPT2180
      IF(MMFL.EQ.1) GOTO 1080                                            IMPT2190
      IF(MBFL.NE.1) GO TO 915                                            IMPT2200
      NUMB = NUMB+1                                                      IMPT2210
      IF(NUMB.NE.2) GOTO 915                                             IMPT2220
      EFLN(NB) = 0.99* RX/EST                                            IMPT2230
      GOTO 1060                                                          IMPT2240
  915 CONTINUE                                                           IMPT2250
      IF (MKF(MTI+I-1).NE.NB) GO TO 1057                                 IMPT2260
      RX=RX+RL(MTI+I-1)                                                  IMPT2270
      P=EST-RX/EFLN(NB)                                                  IMPT2280
      IF(P.LE.0.0) GO TO 1057                                            IMPT2290
      LT(KL+1) = MTI+I                                                   IMPT2300
      PK(KL+1) = P                                                       IMPT2310
      DO 905 NC= 1,NBCOND                                                IMPT2320
      IF(LT(KL+1).NE.NODEB(NC)) GOTO 905                                 IMPT2330
      MBC(1) = MBC(1)+1                                                  IMPT2340
      MBC(MBC(1)+1) = NODEB(NC)                                          IMPT2350
      MBFL=1                                                             IMPT2360
      GOTO 925                                                           IMPT2370
  905 CONTINUE                                                           IMPT2380
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  925 CONTINUE                                                   IMPT2390
      KL= KL +1                                                  IMPT2400
 1055 CONTINUE                                                   IMPT2410
 1057 L=KIR+1                                                    IMPT2420
      M = KIR                                                    IMPT2430
      IF3 = IF3 +KL                                              IMPT2440
      IF2 = MNEL(NB-1)                                           IMPT2450
      IFF=MNEL(NB-1) -KL +IFF                                    IMPT2460
      IF (KL.EQ.0) GO TO 1080                                    IMPT2470
       KIR = KIR +KL                                             IMPT2480
      DO 1056 I = L,KIR                                          IMPT2490
      BET(KIL+I) = PK(I-M)                                       IMPT2500
 1056 MNOD(KIL+I) = LT(I-M)                                      IMPT2510
 1080 CONTINUE                                                   IMPT2520
      JER= JER+IF2                                               IMPT2530
      IF (JER.GT.IK) GO TO  306                                  IMPT2540
      SSR(KIR+1-IF3) = SSR(KIR-IF3) +RL(JER)                     IMPT2550
      IF(EFLN(MEF).LE.SSR(KIR+1-IF3)) GOTO 306                   IMPT2560
      KIR = KIR +1                                               IMPT2570
      MNOD(KIL+KIR) = NVEC(JER,2)                                IMPT2580
  305  CONTINUE                                                  IMPT2590
  306 CONTINUE                                                   IMPT2600
      IF(KIL.LE.1.AND.KIR.LE.1) GOTO 308                         IMPT2610
      IF(MIML.NE.0) GOTO 307                                     IMPT2620
       BET(1)=PAX            *BET(2)/PAL                         IMPT2630
      MNOD(1) = NVEC(IBIG,1)                                     IMPT2640
      DO 971 J=1,NBCOND                                          IMPT2650
      IF(MNOD(1).NE.NODEB(J)) GOTO 971                           IMPT2660
      MBC(1) = MBC(1) +1                                         IMPT2670
      MBC(MBC(1)+1) = NODEB(J)                                   IMPT2680
  971 CONTINUE                                                   IMPT2690
       GO TO 307                                                 IMPT2700
 304   IF(MIML.EQ.0) GO TO 308                                   IMPT2710
      IF(KIL.LE.1.AND.KIR.LE.1) GOTO 308                         IMPT2720
       BET(KIL+1)=PAL*BET(KIL)/PAX                               IMPT2730
      MNOD(KIL+1) = NVEC(IBIG,2)                                 IMPT2740
```

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```
      DO 972 J=1,NBCOND                                                 IMPT2750
      IF(MNOD(KIL+1).NE.NODEB(J)) GOTO 972                              IMPT2760
      MBC(1) = MBC(1) +1                                                IMPT2770
      MBC(MBC(1)+1) = NODEB(J)                                          IMPT2780
  972 CONTINUE                                                          IMPT2790
       GO TO 307                                                        IMPT2800
  308  BET(1)=PAX                                                       IMPT2810
       BET(2)=PAL                                                       IMPT2820
      MNOD(1) = NVEC(IBIG,1)                                            IMPT2830
      MNOD(2) = NVEC(IBIG,2)                                            IMPT2840
      DO 973 J= 1,NBCOND                                                IMPT2850
      IF(MNOD(1).NE.NODEB(J)) GOTO 974                                  IMPT2860
      MBC(1) = MBC(1) +1                                                IMPT2870
      MBC(MBC(1)+1) = NODEB(J)                                          IMPT2880
  974 IF(MNOD(2) .NE.NODEB(J)) GOTO 973                                 IMPT2890
      MBC(1) = MBC(1) +1                                                IMPT2900
      MBC(MBC(1)+1) = NODEB(J)                                          IMPT2910
  973 CONTINUE                                                          IMPT2920
  307  KII=KIL+KIR                                                      IMPT2930
       SUM=0.                                                           IMPT2940
       DO 311 J=1,KII                                                   IMPT2950
  311  SUM=SUM+BET(J)                                                   IMPT2960
C    BET = WEIGHTING FACTOR FOR THE EFFECTED NODES                      IMPT2970
       DO 312 J=1,KII                                                   IMPT2980
      BET(J) = BET(J)/SUM                                               IMPT2990
      IF(MBC(1).EQ.0) GO TO 312                                         IMPT3000
      L= MBC(1)+1                                                       IMPT3010
      DO 989 I= 2,L                                                     IMPT3020
      IF(MNOD(J).EQ.MBC(I)) BET(J)=0.0                                  IMPT3030
  989 CONTINUE                                                          IMPT3040
  312 CONTINUE                                                          IMPT3050
  936 CONTINUE                                                          IMPT3060
      DO 101 I=1,JNBR                                                   IMPT3070
  101 EFLN(I) = EF(I)                                                   IMPT3080
       SUMB=0.                                                          IMPT3090
       DO 313 J=1,KII                                                   IMPT3100
```

```
      JEE= MNOD(J)                                                      IMPT3110
       IF(ICP.GT.0.AND.JEE.GT.IK) JEE=JEE-IK                            IMPT3120
       SUMB=SUMB+BET(J)**2/RMASS(JEE)                                   IMPT3130
 313   CONTINUE                                                         IMPT3140
       B1=1./FMASS(JBIG)+(FH(JBIG)/2.)**2/FMOI(JBIG)+SUMB               IMPT3150
       B2=1./FMASS(JBIG)+SUMB                                           IMPT3160
       SUMN=0.                                                          IMPT3170
       SUMT=0.                                                          IMPT3180
      DO 340 J=1,KII                                                    IMPT3190
      JEE= MNOD(J)                                                      IMPT3200
       IF(ICP.GT.0.AND.JEE.GT.IK) JEE=JEE-IK                            IMPT3210
C     ESTABLISH THE TANGENTIAL AND NORMAL VELOCITIES OF RING AND FRAGMENTIMPT3220
      SUMN=SUMN +BET(J)*(VW(JEE)*RCOS-VU(JEE)*RSIN)                     IMPT3230
  340 SUMT=SUMT + BET(J)*(VW(JEE)*RSIN+VU(JEE)*RCOS)                    IMPT3240
      VFN= VELFW(JBIG)*RCOS - VELFU(JBIG)*RSIN                          IMPT3250
      VFT= VELFW(JBIG) * RSIN  + VELFU(JBIG)*RCOS                       IMPT3260
C    SINT= RELATIVE TANGENTIAL VEL BETWEEN RING AND FRAG., AINT IS REL. NIMPT3270
      SINT= VFT-VELFA(JBIG)*FH(JBIG) /2.0 -SUMT                         IMPT3280
      AINT=VFN-SUMN                                                     IMPT3290
C    IF AINT LE 0 THE FRAG IS NOT APPROACHING THE RING SO SKIP OUT OF THEIMPT3300
      IF(AINT.GT.0.0) GOTO 3005                                         IMPT3310
      WRITE(MWRITE,3006) AINT                                           IMPT3320
 3006 FORMAT('0AINT=',D15.6,'    NO IMPACT--LEAVING IMPCTE')            IMPT3330
      GOTO 350                                                          IMPT3340
 3005 CONTINUE                                                          IMPT3350
      IF(UNK(JBIG).EQ.0.0)GO TO 702                                     IMPT3360
C    CALCULATE THE EFFECT OF FRICTION ON THE RELATIVE VELOCITIES AND THE IMPT3370
       TANX=SINT*B2/(AINT*B1)                                           IMPT3380
705   IF(UNK(JBIG).LE.TANX)GO TO 706                                    IMPT3390
      APN=(1.0+CR(JBIG))*AINT/B2                                        IMPT3400
       APT=SINT/B1                                                      IMPT3410
      GO TO 760                                                         IMPT3420
 706   APN=(1.+CR(JBIG))*AINT/B2                                        IMPT3430
      APT=UNK(JBIG)*APN                                                 IMPT3440
      GO TO 760                                                         IMPT3450
702   APN=(1.0+CR(JBIG))*AINT/B2                                        IMPT3460
```

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```
      APT=0.0                                                           IMPT3470
  760 CONTINUE                                                          IMPT3480
      FACTFN=-1.0*APN/FMASS(JBIG)                                       IMPT3490
      FACTFT=-1.0*APT/FMASS(JBIG)                                       IMPT3500
      FACTFO=APT*FH(JBIG)/FMOI(JBIG)/2.0                                IMPT3510
C   UPDATE THE RING AND FRAGMENT VELOCITIES                             IMPT3520
      VELFU(JBIG) = (-FACTFN*RSIN+FACTFT*RCOS) +VELFU(JBIG)             IMPT3530
      VELFW(JBIG) =(FACTFN*RCOS+FACTFT*RSIN) +VELFW(JBIG)               IMPT3540
      VELFA(JBIG) = FACTFO +VELFA(JBIG)                                 IMPT3550
       DO 350 J=1,KII                                                   IMPT3560
      JEE= MNOD(J)                                                      IMPT3570
       IF(ICP.GT.0.AND.JEE.GT.IK) JEE=JEE-IK                            IMPT3580
       FACTN=BET(J)*APN/RMASS(JEE)                                      IMPT3590
       FACTT=BET(J)*APT/RMASS(JEE)                                      IMPT3600
      VU(JEE)= (-FACTN*RSIN+FACTT*RCOS) +VU(JEE)                        IMPT3610
      VW(JEE) = (FACTN*RCOS+FACTT*RSIN) +VW(JEE)                        IMPT3620
      JVEL(JEE)= 1                                                      IMPT3630
  350  CONTINUE                                                         IMPT3640
      RETURN                                                            IMPT3650
      END                                                               IMPT3660
```

```
      SUBROUTINE PENTRN(TU,TW,TFCGU,TFCGW,NPP,PMAX,NEF,NEQ,JF,PAL,RL     PENT0010
     2,IBIG,H,FH,IK,NF,ICP,PD,PALE)                                      PENT0020
      IMPLICIT REAL*8(A-H,O-Z)                                           PENT0030
      DIMENSION PND(51,6),PD(50,6),PALE(50,6)                            PENT0040
      DIMENSION TU(1),TW(1),TFCGU(1),TFCGW(1),NEF(1),RL(1),H(51,3),FH(1)PENT0050
      COMMON /TAPE/ MWRITE,MREAD,MPUNCH                                  PENT0060
      COMMON/BR/ NVEC(51,2), LMT(51)                                     PENT0070
C     CHECK FOR NODAL IMPACT AND ELEMENT IMPACT                          PENT0080
      DO 110 IF = 1,NF                                                   PENT0090
      L=1                                                                PENT0100
      DO 100 IR=1,IK                                                     PENT0110
      PD(IR,IF) = -10.0                                                  PENT0120
      PND(IR,IF)  = -10.0                                                PENT0130
      L1= NVEC(IR,1)                                                     PENT0140
      L2=NVEC(IR,2)                                                      PENT0150
      IF(IR.NE.LMT(L)) GO TO 90                                          PENT0160
      L=L+1                                                              PENT0170
      GO TO 100                                                          PENT0180
   90 CONTINUE                                                           PENT0190
C CALCULATE DIST FROM FRAG TO NODE1 -- DFN AND LENGTH OF ELEMENT  DEL    PENT0200
      DFN=DSQRT((TFCGU(IF)-TU(L1))**2+(TFCGW(IF)-TW(L1))**2)             PENT0210
      DEL=DSQRT((TU(L2)-TU(L1))**2+(    TW(L2)-TW(L1))**2)               PENT0220
      RL(IR) = DEL                                                       PENT0230
      THICK = 0.0                                                        PENT0240
      DO 400  J=1,3                                                      PENT0250
  400 THICK= THICK+ (H(L1,J)+H(L2,J))/2.0                                PENT0260
C   DCRTN IS THE CRITICAL DISTANCE = HALF ( FRAG DIA. + AVG ELEMENT THICPENT0270
      DCRTN= (FH(IF)+THICK)/2.0                                          PENT0280
      DCRTE=DCRTN                                                        PENT0290
      DU= TU(L1)-TFCGU(IF)                                               PENT0300
      DW = TW(L1) - TFCGW(IF)                                            PENT0310
      DEU= TU(L2) -TU(L1)                                                PENT0320
      DEW= TW(L2) - TW(L1)                                               PENT0330
      TCOS = DEU / DEL                                                   PENT0340
      TSIN = DEW/ DEL                                                    PENT0350
      PAL = -(DU*TCOS+DW*TSIN)                                           PENT0360
```

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```
      PALE(IR,IF) = PAL                                                 PENT0370
       IF (PAL.LT.0.0) GO TO 100                                        PENT0380
      IF (PAL.GT.DEL) GO TO 100                                         PENT0390
      DFE= -(-DW*TCOS+ DU*TSIN)                                         PENT0400
       PD(IR,IF) = DCRTF-DFE                                            PENT0410
  100 CONTINUE                                                          PENT0420
  110 CONTINUE                                                          PENT0430
C   CALCULATE THE LARGEST PENETRATION DIST, AND NUMBER OF + PENETRATIONSPENT0440
      K = 0                                                             PENT0450
      IF (ICP.GT.0) K=1                                                 PENT0460
      DO 290 J=1,NF                                                     PENT0470
  290 NEF(J) = 0                                                        PENT0480
      NEQ=0                                                             PENT0490
      PMAX= -5.0                                                        PENT0500
      NPP = 0                                                           PENT0510
      PAL = -1.5                                                        PENT0520
      DO 300 IR=1,IK                                                    PENT0530
      L1= NVEC(IR,1)                                                    PENT0540
      L2= NVEC(IR,2)                                                    PENT0550
      DO 300 IF= 1,NF                                                   PENT0560
  335 IF(PD(IR,IF).GT.0.0) NPP=NPP+1                                    PENT0570
      IF(PD(IR,IF)-PMAX) 360 ,350,340                                   PENT0580
  340 PMAX= PD(IR,IF)                                                   PENT0590
      PAL = PALE(IR,IF)/ RL(IR)                                         PENT0600
      IBIG = IR                                                         PENT0610
      NEQ=0                                                             PENT0620
      JF=IF                                                             PENT0630
      DO 345 J=1,NF                                                     PENT0640
  345 NEF(J) =0                                                         PENT0650
      GO TO 360                                                         PENT0660
  350 NEF(IF) =1                                                        PENT0670
      NEQ= NEQ+1                                                        PENT0680
  360 CONTINUE                                                          PENT0690
  300 CONTINUE                                                          PENT0700
      RETURN                                                            PENT0710
      END                                                               PENT0720
```

```
      SUBROUTINE PRINT(IT,TIME,HINN,HOUT,APDEN,SPRIN,BMASS,C2,NQR,
     *CINETO,BEP,WET,NV,ES,ASFL,SNS,NV1,NV2,NV3,SOL,QVEL)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION ASFL(NV1,3,NV2,NV3),SNS(NV1,3,NV2,NV3)
      DIMENSION AB(18), ES(3,6,6),SOL(1),QVEL(1),CINETF(3)
      DIMENSION CCPY(51),COPZ(51),BEPS(3)
     *,BEP(50,3,3,8),WET(50,3),HINN(50,3),HOUT(50,3),FKTP(3)
     *, FQREF(204),BMASS(1),CINE(205),SPRIN(1),FAILI(50),FAILO(50)
      COMMON/VQ/ FLVA(205),DISP(205),DELD(205),BINP(50,3),BIMP(50,3)
      COMMON/FC/ Y(51),Z(51),ANG(51),H(51,3)
      COMMON /FRAGV/ UDOT(3),WDOT(3),ADOT(3)
      COMMON /FRAG/ FH(3),FMASS(3),FMOI(3),UNK(3),CR(3),FCGU(3),FCGW(3)
     *,ALFA(3),DFCGU(3),DFCGW(3),DALFA(3),TREL,FKT(3),DELTAT,NF,MIMP
      COMMON /EP/ EPSI(50),EPSO(50)
      COMMON /FG/ IK,IKK,ICP,LREF,NOGA,NFL,NI,ICOL(205),INUM(205)
     *,NBCOND,NBC(7),NODEB(7),KROW(8),NDEX(8),NIRREG
      COMMON/MAT/YOUNG(3,6),DS(3,6),SNO(3,5,6),NSFL(3,6),P(3,6),NLAY
      COMMON /IIAT/ TAII, IMCOU
      COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      COMMON /TAM/ MKE(51)
      SIN(Q)=DSIN(Q)
      COS(Q)=DCOS(Q)
      WRITE (MWRITE,1200) IT
 1200 FORMAT(///,' ENERGY AND WORK AT THE END OF TIME CYCLE',I5)
      WRITE(MWRITE,1205)
 1205 FORMAT('0          FRAGMENT',10X,'KINETIC ENERGY',/)
      CINETT=0.0
      DO 1210 I=1,NF
      CINETF(I)=FMASS(I)/2.0*(UDOT(I)**2+WDOT(I)**2)+FMOI(I)/2.0*
     @(ADOT(I)**2)
      CINETT= CINETT+(FKT(I)-CINETF(I))
      WRITE(MWRITE,1215) I,CINETF(I)
 1215 FORMAT(' ',10X,I5,13X,D15.6)
 1210 CONTINUE
      CINET=0.0
      DO 701 I=1,NI
```


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```
  701 CINET= CINET+(QVEL(I)**2*SOL(I))/2.0D+00
       ELAST=0.0
       DO 702 IR=1,IK
      I=MKE(IR)
      NLAP = NLAY
      IF(MKE(IR).GT.1) NLAP = 1
       DO 703 J=1,NOGA
       SUM=0.0
      DO 801 M=1,NLAP
      NSFLM=NSFL(M,I)
      DO 801 N=1,NFL
      STRS=0.0
       K=N+(M-1)*NFL
      DO 802 L=1,NSFLM
      LL= L+1
      AB(K)= (ES(M,L,I)-ES(M,LL,I))/ ES(M,1,I)
  802 STRS=STRS+SNS(IR,J,K,L)* AB(K)
      STRS= STRS**2
  801 SUM = SUM+STRS*ASFL(IR,J,K,NSFLM)/(AB(K)*YOUNG(M,I))
  703 ELAST= ELAST+(SUM*WET(IR,J))/2.0
 702   CONTINUE
       SPDEN=0.0
       IF(NQR .EQ. 0) GO TO 31
       DO 30 I=1,NI
 30    FQREF(I)=0.0
       CALL OMULT(SPRIN,DISP,ICOL,NI,FQREF,KROW,NDEX,NIRREG)
       DO 32 I=1,NI
 32    SPDEN=SPDEN+DISP(I)*FQREF(I)
       SPDEN=SPDEN/2.
   31 CONTINUE
       PLAST=CINETT-CINET-ELAST-SPDEN
      TAIIT= TIME - TAII
      WRITE(MWRITE,1) IT ,TIME,TAIIT,CINETT,CINET,ELAST,PLAST
    1 FORMAT('-    J=',I5,'       TIME (SEC.) =',D15.6,5X,'TIME AFTER INIT
     *IAL IMPACT =',D15.6,/,
     *'    WORK INPUT INTO RING (IN.-LB.)    =',E15.6,/,
```

```
     *'    RING KINETIC ENERGY  (IN.-LB.)     =',E15.6,/,
     *'    RING ELASTIC ENERGY  (IN.-LB.)     =',E15.6,/,
     *'    RING PLASTIC WORK    (IN.-LB.)     =',E15.6)
       IF(NQR .EQ. 0) GO TO 33
       WRITE(MWRITE,34) SPDEN
 34    FORMAT('    ENERGY STORED IN THE ELASTIC RESTRAINTS (IN.-LB.)  =',
     *E15.6)
 33    DO 11 I=1,IKK
       COPY(I)=Y(I)+DISP(I*4-3)*COS(ANG(I))-DISP(I*4-2)*SIN(ANG(I))
 11    COPZ(I)=Z(I)+DISP(I*4-3)*SIN(ANG(I))+DISP(I*4-2)*COS(ANG(I))
       IKP1=IK+1
       WRITE(MWRITE,2)
 2     FORMAT(/,'    I ',5X,'V',11X,'W',9X,'PSI',9X,'CHI',10X,'COPY',
     *8X,'COPZ',9X,'L',11X,'M',7X,'STRAIN(IN)',4X,'STRAIN(OUT)')
 50    DO 21 I=1,IK
 21    WRITE(MWRITE,22)I,DISP(I*4-3),DISP(I*4-2),DISP(I*4-1),DISP(I*4),
     *COPY(I),COPZ(I),BINP(I,2),BIMP(I,2),EPSI(I),EPSO(I)
 22    FORMAT(I5,9E12.4,2X,E12.4)
       IF(ICP.GT.0) GO TO 57
       WRITE(MWRITE,24) IKP1,DISP(IKP1*4-3),DISP(IKP1*4-2),
     *DISP(IKP1*4-1),DISP(IKP1*4),COPY(IKP1),COPZ(IKP1),EPSI(IKP1),
     @EPSO(IKP1)
  24  FORMAT(I5,6D12.4,24X,D12.4,D14.4)
 57    CONTINUE
      WRITE(MWRITE,35)
  35  FORMAT(10X,'FRAG NO.=',5X,'FCGU =',9X,'FCGW =',9X,'ALFA =',9X,
     *'FRUV =',9X,'FRWV =',9X,'FRAV =',/)
      DO 36 I=1,NF
  36  WRITE(MWRITE,37) I,FCGU(I),FCGW(I),ALFA(I),UDOT(I),WDOT(I),ADOT(I)
  37  FORMAT(10X,I5,3X,6D15.6,/)
       RETURN
      END
```


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SECTION 7

ILLUSTRATIVE EXAMPLES

7.1 JET 5A Example: An Impulsively-Loaded Free Single-Layer Uniform-Thickness Circular Complete Ring without Branches

7.1.1 Problem Description

The geometry of the free-ring structure, as shown in Fig. 11, is a free circular ring, 0.4-in thick, 2.5-in wide, with a mean radius of 7.7-in. The ring is subjected to severe impulsive loading over a peripheral sector of 126 degrees of its exterior. Taking account of the symmetry of the impulsive loading and the ring geometry, only half of the ring is analyzed with the symmetry-prescribed-displacement conditions imposed at the centerline mid-plane. Twenty uniform finite elements are used to model the half ring. To demonstrate the multilayer capability of the JET 5A program, the steel ring is modeled by two identical layers. The inner layer is designated as the reference layer.

The uniaxial stress-strain properties of the 4130 cast steel ring material are represented by a three-mechanical-sublayer model defined by σ_1, ε_1 = 80,950 psi, .00279; σ_2, ε_2 = 105,300 psi, .0225; and σ_3, ε_3 = 121,000 psi, .2000, with an elastic modulus of $29\text{x}10^6$ psi and a yield stress of 80,950 psi. The strain rate constants are $D = 40.4$ sec^{-1} and $p = 5$, and the mass density is taken to be $0.733085\text{x}10^{-3}$ (lb-sec^2/in^4).

The impulse is modeled by an initial inward "uniform" velocity of 10,000 in/sec. In order to represent adequately the impulse at the end of the loaded region (an impulse assumed to be generated by a high explosive detonation), the last node has half the "uniform" normal velocity plus a rotational component (see Fig. 11).

The JET 5A program will predict the resulting transient structural response by using a time step of 4 microseconds. Printout will be given every 10 time steps or cycles of computation until 150 cycles have been completed.

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7.1.2 Input Data

The values to be punched on the data cards are as follows:

Card 1 — 10I5

IK = 20

ICP = 0

NLAY = 2

LREF = 1

NOGA = 3

NFL = 4

MM = 150

M1 = 10

M2 = 10

ICON = 0

Card 2 — 3I5

NSFL(1,1) = 3

NSFL(2,1) = 3

Card 3A — 3D15.6

DENS(1,1) = 0.733085D-03

DS(1,1) = 0.404000D+02

P(1,1) = 0.500000D+01

Card 4AA — 4D15.6

EPS(1,1,1) = 0.279000D-02

SIG(1,1,1) = 0.809500D+05

EPS(1,2,1) = 0.225000D-01

SIG(1,2,1) = 0.105300D+06

Card 4AB — 4D15.6

EPS(1,3,1) = 0.200000D+00

SIG(1,3,1) = 0.121000D+06

Card 3B — 3D15.6

DENS(2,1) = 0.733085D-03

DS(2,1) = 0.404000D+02

P(2,1) = 0.500000D+01

Card 4BA 4D15.6

EPS(2,1,1) = 0.279000D-02

SIG(2,1,1) = 0.809500D+05

EPS(2,2,1) = 0.225000D-01

SIG(2,2,1) = 0.105300D+06

Card 4BB 4D15.6

EPS(2,3,1) = 0.200000D+00

SIG(2,3,1) = 0.121000D+06

Card 5 2D15.6

B(1) = 0.250000D+01

DELTAT = 0.400000D-05

Card 6A 3D15.6

Y(1) = 0.0

Z(1) = 0.770000D+01

ANG(1) = 0.0

.
.
.

Additional cards are punched until all the nodes are described.

.
.
.

Y(21) = 0.0

Z(21) = -0.770000D+01

ANG(21) = 0.0

Card 7A 5D15.6

H(1,1) = 0.200000D+00

H(1,2) = 0.200000D+00

H(2,1) = 0.200000D+00

.
.
.

Additional cards are punched until all the nodal thicknesses for each layer are described, five per card.

.
.
.

H(21,1) = 0.200000D+00

H(21,2) = 0.200000D+00

Card 8A I5

NDIS = 0

Card 9 I5

NBR = 0

Card 10 3I5

NOP = 3

NASP = 1

NTERF = 1

Card 10A 2I5,D15.6

NSBS(1) = 1

NSEL(1) = 20

AZET(1) = 0.570000D+00

Card 11 3D25.16

AXG(1) = 0.1127016653792585D+00

AXG(2) = 0.5000000000000000D+00

AXG(3) = 0.8872983346207415D+00

Card 12 3D25.16

AWG(1) = 0.2777777777777778D+00

AWG(2) = 0.4444444444444444D+00

AWG(3) = 0.2777777777777778D+00

Card 13A 3D25.16

TXG(1) = -0.861136311594053D+00

TXG(2) = -0.3399810435848560D+00

TXG(3) = 0.3399810435848560D+00

Card 13B D25.16

TXG(4) = 0.861136311594053D+00

Card 14A 3D25.16

TWG(1) = 0.3478548451374540D+00

TWG(2) = 0.6521451548625460D+00

TWG(3) = 0.6521451548625460D+00

Card 14B D25.6

TWG(4) = 0.3478548451374540D+00

Card 15 5I5

NBCOND = 2

NBC(1) = 1

NODEB(1) = 1

NBC(2) = 1

NODEB(2) = 21

Card 16 I5

NQR = 0

Card 17 4I5

NV = 1

IOTA = 1

IOTB = 0

IOTC = 0

Card 18A 2I5

IE1 = 1

IE2 = 7

Card 18AA 5D15.6

WRAD = -0.100000D+05

WRAD1 = 0.100000D+05

ANGV1 = 0.0

WARD2 = -0.500000D+04

ANGV1 = 0.200000D+05

Card 21 2D15.6

TBEGIN = 0.0

TFINAL = 0.0

Card 26 I5

ICONT = 0

THIS IS THE INPUT DECK FOR EXAMPLE 7.1

```
 20     0     2     1     3     4   150    10    10     0
  3     3
00.733085D-03  00.404000D+02  00.500000D+01
00.279000D-02  00.809500D 05  00.225000D-01  00.105300D 06
00.200000D 00  00.121000D 06
00.733085D-03  00.404000D+02  00.500000D+01
00.279000D-02  00.809500D 05  00.225000D-01  00.105300D 06
00.200000D 00  00.121000D 06
00.250000D+01  00.400000D-05
 0.0000000D000   0.770000D 01   0.000000D 00   0.400000D 00
 0.120455D 01  00.760520D 01  -0.900000D 01  00.400000D 00
00.237943D 01  00.732314D 01  -0.180000D 02  00.400000D 00
00.349573D 01  00.686075D 01  -0.270000D 02  00.400000D000
00.452595D 01  00.622943D 01  -0.360000D 02  00.400000D 00
00.544472D 01  00.544472D 01  -0.450000D 02  00.400000D 00
00.622943D 01  00.452595D 01  -0.540000D 02  00.400000D 00
00.686075D 01  00.349573D 01  -0.630000D 02  00.400000D 00
00.732314D 01  00.237943D 01  -0.720000D 02  00.400000D 00
00.760520D 01  00.120455D 01  -0.810000D 02  00.400000D 00
00.770000D 01  00.0           -0.900000D 02  00.400000D 00
00.760520D 01  -0.120455D 01  -0.990000D 02  00.400000D 00
00.732314D 01  -0.237943D 01  -0.108000D 03  00.400000D 00
00.686075D 01  -0.349573D 01  -0.117000D 03  00.400000D 00
00.622943D 01  -0.452595D 01  -0.126000D 03  00.400000D 00
00.544472D 01  -0.544472D 01  -0.135000D 03  00.400000D 00
00.452595D 01  -0.622943D 01  -0.144000D 03  00.400000D 00
00.349573D 01  -0.686075D 01  -0.153000D 03  00.400000D 00
00.237943D 01  -0.732314D 01  -0.162000D 03  00.400000D 00
00.120455D 01  -0.760520D 01  -0.171000D 03  00.400000D 00
00.0           -0.770000D+01  00.180000D 03  00.400000D 00
00.200000D+00  00.200000D+00  00.200000D+00  00.200000D+00  00.200000D+00
00.200000D+00  00.200000D+00  00.200000D+00  00.200000D+00  00.200000D+00
00.200000D+00  00.200000D+00  00.200000D+00  00.200000D+00  00.200000D+00
00.200000D+00  00.200000D+00  00.200000D+00  00.200000D+00  00.200000D+00
00.200000D+00  00.200000D+00  00.200000D+00  00.200000D+00  00.200000D+00
00.200000D+00  00.200000D+00  00.200000D+00  00.200000D+00  00.200000D+00
```

ORIGINAL PAGE IS OF POOR QUALITY

```
00.200000D+00   00.200000D+00   00.200000D+00   00.200000D+00   00.200000D+00
00.200000D+00   00.200000D+00   00.200000D+00   00.200000D+00   00.200000D+00
00.200000D+00   00.200000D+00
  0
  0
  3    1    1
  1   20   00.570000D+00
00.1127016653792585D+00   00.5000000000000000D+00   00.8872983346207415D+00
00.2777777777777778D+00   00.4444444444444444D+00   00.2777777777777778D+00
-0.8611363115940530D+00   -0.3399810435848560D+00   00.3399810435848560D+00
00.8611363115940530D+00
00.3478548451374540D+00   00.6521451548625460D+00   00.6521451548625460D+00
00.3478548451374540D+00
  2    1    1    1   21
  0
  1    1    0    0
  1    7
-0.100000D+05   -0.100000D+05   00.0           -0.500000D+04   00.200000D+05
00.0            00.0
  0
```

7.1.3 Solution Output Data

The following is the output for 600 microseconds of response of the ring to the given initial velocity distribution.

The first segment of output gives a breakdown of the initial geometry of the ring and the initial loading parameters. A calculation of a guideline time step size is made and is presented to compare with the user-generated time step.

Strain information is printed at each spanwise Gaussian station, at each designated strain point (inner and outer surface and each interface), and at each node (inner and outer surface). The maximum strain is 12.39 per cent and occurs on the outer surface of element 9 at 600 microseconds after initial loading.

In the interest of conciseness, only a portion of the called-for output is given. Included are (1) all input verification information and (2) scheduled output at the end of time cycles 0, 1, 10, 20, 30, 40, 50, 140, and 150 (last). This output listing is intended for use in verification of the adaptation of the JET 5A computer code to other computing facilities.

THIS IS RUN NUMBER 1 FOR THIS JET 5A SUBMITTAL

THERE ARE NO BRANCHES CONNECTED TO THE MAIN STRUCTURE ,THEREFORE
THE NUMBERING SYSTEM FOR NODES AND ELEMENTS REMAINS UNCHANGED

ADDITIONAL STRAIN POINT	ELEMENT	S COORDINATE
1	20	0.570000D+00

*********** A SPATIAL FINITE ELEMENT AND HOUBOLT TEMPORAL OPERATOR PROGRAM
USED TO CALCULATE THE NONLINEAR RESPONSES OF A VARIABLE THICKNESS MULTILAYER
ARBITRARILY CURVED PARTIAL RING WITH THE FOLLOWING PARAMETERS

PROPERTIES OF THE MAIN STRUCTURE:
WIDTH OF RING (IN) = 0.250000D+01
NUMBER OF ELEMENTS = 20
NUMBER OF SPANWISE GAUSSIAN POINTS = 3
NUMBER OF DEPTHWISE GAUSSIAN POINTS = 4
NUMBER OF LAYERS = 2
REFERENCE SURFACE IS THE MIDDLE SURFACE OF LAYER= 1

MATERIAL PROPERTIES OF LAYER = 1
DENSITY(LB-SEC**2/IN**4) = 0.733085D-03
NUMBER OF MECHANICAL SUBLAYERS = 3

	STRAIN	STRESS
1	0.279000D-02	0.809500D+05
2	0.225000D-01	0.105300D+06
3	0.200000D+00	0.121000D+06

MATERIAL IS STRAIN RATE SENSITIVE WITH
D = 0.404000D+02 P = 0.500000D+01

258

MATERIAL PROPERTIES OF LAYER = 2
DENSITY(LB-SEC**2/IN**4) = 0.733085D-03
NUMBER OF MECHANICAL SUBLAYERS = 3

	STRAIN	STRESS
1	0.279000D-02	0.809500D+05
2	0.225000D-01	0.105300D+06
3	0.200000D+00	0.121000D+06

MATERIAL IS STRAIN RATE SENSITIVE WITH
D = 0.404000D+02 P = 0.500000D+01

SYMMETRY DISPLACEMENT CONDITION AT NODE = 1
SYMMETRY DISPLACEMENT CONDITION AT NODE = 21

THERE ARE NO ELASTIC SPRING CONSTRAINTS

NODE NO	Y COORD(IN)	Z COORD(IN)	SLOPE (RAD)	RING THICKNESS(IN)		
				LAYER 1	LAYER 2	LAYER 3
1	0.0	0.770000D+01	0.0	0.200000D+00	0.200000D+00	
2	0.120455D+01	0.760520D+01	-0.157080D+00	0.200000D+00	0.200000D+00	
3	0.237943D+01	0.732314D+01	-0.314159D+00	0.200000D+00	0.200000D+00	
4	0.349573D+01	0.686075D+01	-0.471239D+00	0.200000D+00	0.200000D+00	
5	0.452595D+01	0.622943D+01	-0.628319D+00	0.200000D+00	0.200000D+00	
6	0.544472D+01	0.544472D+01	-0.785398D+00	0.200000D+00	0.200000D+00	
7	0.622943D+01	0.452595D+01	-0.942478D+00	0.200000D+00	0.200000D+00	
8	0.686075D+01	0.349573D+01	-0.109956D+01	0.200000D+00	0.200000D+00	
9	0.732314D+01	0.237943D+01	-0.125664D+01	0.200000D+00	0.200000D+00	
10	0.760520D+01	0.120455D+01	-0.141372D+01	0.200000D+00	0.200000D+00	
11	0.770000D+01	0.0	-0.157080D+01	0.200000D+00	0.200000D+00	
12	0.760520D+01	-0.120455D+01	-0.172788D+01	0.200000D+00	0.200000D+00	
13	0.732314D+01	-0.237943D+01	-0.188496D+01	0.200000D+00	0.200000D+00	
14	0.686075D+01	-0.349573D+01	-0.204204D+01	0.200000D+00	0.200000D+00	
15	0.622943D+01	-0.452595D+01	-0.219911D+01	0.200000D+00	0.200000D+00	
16	0.544472D+01	-0.544472D+01	-0.235619D+01	0.200000D+00	0.200000D+00	
17	0.452595D+01	-0.622943D+01	-0.251327D+01	0.200000D+00	0.200000D+00	
18	0.349573D+01	-0.686075D+01	-0.267035D+01	0.200000D+00	0.200000D+00	
19	0.237943D+01	-0.732314D+01	-0.282743D+01	0.200000D+00	0.200000D+00	
20	0.120455D+01	-0.760520D+01	-0.298451D+01	0.200000D+00	0.200000D+00	
21	0.0	-0.770000D+01	0.314159D+01	0.200000D+00	0.200000D+00	

GAUSSIAN STATIONS AND WEIGHTS:

AXG	1	=	0.112701665379259	AWG	1	=	0.277777777777778
AXG	2	=	0.500000000000000	AWG	2	=	0.444444444444444
AXG	3	=	0.887298334620741	AWG	3	=	0.277777777777778
TXG	1	=	-0.861136311594053	TWG	1	=	0.347854845137454
TXG	2	=	-0.339981043584856	TWG	2	=	0.652145154862546
TXG	3	=	0.339981043584856	TWG	3	=	0.652145154862546
TXG	4	=	0.861136311594053	TWG	4	=	0.347854845137454

SIZE OF ASSEMBLED MASS OR STIFFNESS MATRIX= 530

BMASS =

0.10000000D+01	0.0	0.34287581D-03	0.0	0.0	0.10000000D+01	0.0	0.75505336D-05
0.0	0.12204091D-04	0.0	0.29018785D-04	0.0	0.35095693D-04	0.66918944D-03	0.0
0.10050242D-03	0.0	-0.78387076D-05	-0.52264855D-11	0.68574822D-03	0.0	-0.32489809D-04	0.0
0.18415882D-05	-0.14463178D-04	-0.14974942D-09	0.29298228D-04	0.0	-0.78387188D-05	0.0	-0.99851655D-05
-0.99202062D-09	0.15101190D-04	0.80307262D-09	0.24407842D-04	0.12050411D-03	0.29018948D-04	0.77852644D-05	0.35095089D-04
0.66919062D-03	-0.29018822D-04	0.10050120D-03	0.32488749D-04	-0.78385035D-05	-0.70286108D-11	0.68574784D-03	0.77825530D-05
-0.32489155D-04	-0.10417972D-04	0.18415530D-05	-0.14462681D-04	0.20231350D-08	0.29298284D-04	-0.35095128D-04	-0.78388076D-05
-0.18423636D-05	-0.99848921D-05	0.12236227D-08	0.15100685D-04	0.79743497D-09	0.24407891D-04	0.12050526D-03	0.29018711D-04
0.77855963D-05	0.35095721D-04	0.66919172D-03	-0.29018842D-04	0.10050253D-03	0.32489422D-04	-0.78388502D-05	0.40744473D-10
0.68575029D-03	0.77823501D-05	-0.32489891D-04	-0.10418285D-04	0.18415929D-05	-0.14463189D-04	0.43818294D-09	0.29298502D-04
-0.35095883D-04	-0.78385860D-05	-0.18423966D-05	-0.99851905D-05	-0.30122738D-09	0.15101195D-04	0.79341542D-09	0.24408089D-04
0.12050479D-03	0.29018809D-04	0.77854583D-05	0.35095463D-04	0.66918988D-03	-0.29018833D-04	0.10050198D-03	0.32489146D-04
-0.78387061D-05	0.51740621D-10	0.68574748D-03	0.77824352D-05	-0.32489589D-04	-0.10418156D-04	0.18415766D-05	-0.14462788D-04
0.53643651D-09	0.29298227D-04	-0.35095573D-04	-0.78386789D-05	-0.18423831D-05	-0.99850683D-05	-0.20064639D-09	0.15100789D-04
0.79030193D-09	0.24407828D-04	0.12050439D-03	0.29018756D-04	0.77856132D-05	0.35095184D-04	0.66918751D-03	-0.29018948D-04
0.10050153D-03	0.32488903D-04	-0.78388711D-05	0.10124117D-10	0.68574728D-03	0.77822375D-05	-0.32489388D-04	-0.10418061D-04
0.18415663D-05	-0.14463454D-04	0.86470085D-09	0.29298060D-04	-0.35095375D-04	-0.78384692D-05	-0.18423682D-05	-0.99849657D-05
0.10377000D-09	0.15101466D-04	0.79885411D-09	0.24407676D-04	0.12050439D-03	0.29018946D-04	0.77852345D-05	0.35095270D-04
0.66918988D-03	-0.29018776D-04	0.10050153D-03	0.32488920D-04	-0.78384709D-05	-0.31878774D-10	0.68574748D-03	0.77826141D-05
-0.32489315D-04	-0.10418044D-04	0.18415614D-05	-0.14462783D-04	0.12722434D-08	0.29298209D-04	-0.35095289D-04	-0.78388718D-05
-0.18423732D-05	-0.99849657D-05	0.40765418D-09	0.15100791D-04	0.80383476D-09	0.24407828D-04	0.12050479D-03	0.29018822D-04
0.77854332D-05	0.35095469D-04	0.66919172D-03	-0.29018821D-04	0.10050198D-03	0.32489147D-04	-0.78386796D-05	-0.20681772D-10
0.68575029D-03	0.77824602D-05	-0.32489584D-04	-0.10418155D-04	0.18415762D-05	-0.14463185D-04	0.13293194D-08	0.29298490D-04
-0.35095568D-04	-0.78387056D-05	-0.18423834D-05	-0.99850683D-05	0.50851487D-09	0.15101196D-04	0.80259907D-09	0.24408089D-04
0.12050526D-03	0.29018836D-04	0.77853475D-05	0.35095778D-04	0.66919062D-03	-0.29018729D-04	0.10050253D-03	0.32489433D-04
-0.78385873D-05	0.26826920D-10	0.68574784D-03	0.77825975D-05	-0.32489843D-04	-0.10418273D-04	0.18415897D-05	-0.14462682D-04
-0.20142189D-09	0.29298286D-04	-0.35095826D-04	-0.78388504D-05	-0.18423999D-05	-0.99851905D-05	-0.10167024D-08	0.15100685D-04
0.79611715D-09	0.24407891D-04	0.12050411D-03	0.29018804D-04	0.77855518D-05	0.35095023D-04	0.66918944D-03	-0.29018953D-04
0.10050120D-03	0.32488736D-04	-0.78388073D-05	0.25307494D-10	0.68574822D-03	0.77822672D-05	-0.32489210D-04	-0.10417985D-04
0.18415567D-05	-0.14463183D-04	0.19134890D-08	0.29298241D-04	-0.35095193D-04	-0.78385020D-05	-0.18423598D-05	-0.99848921D-05
0.11993319D-08	0.15101189D-04	0.79309534D-09	0.24407842D-04	0.12050517D-03	0.29018779D-04	0.77854721D-05	0.35095690D-04
0.66919274D-03	-0.29018796D-04	0.10050242D-03	0.32489370D-04	-0.78387193D-05	0.99963384D-11	0.68575089D-03	0.77824629D-05
-0.32489811D-04	-0.10418254D-04	0.18415883D-05	-0.14463076D-04	0.89093887D-09	0.29298594D-04	-0.35095798D-04	-0.78387070D-05
-0.18423951D-05	-0.99851655D-05	0.10359583D-09	0.15101083D-04	0.79768562D-09	0.24408182D-04	0.12050517D-03	0.29018785D-04
0.77854610D-05	0.35095693D-04	0.66918944D-03	-0.29018791D-04	0.10050242D-03	0.32489370D-04	-0.78387076D-05	-0.52264855D-11
0.68574822D-03	0.77824740D-05	-0.32489809D-04	-0.10418253D-04	0.18415882D-05	-0.14463178D-04	-0.14974942D-09	0.29298228D-04
-0.35095795D-04	-0.78387188D-05	-0.18423952D-05	-0.99851655D-05	-0.99202062D-09	0.15101190D-04	0.80307262D-09	0.24407842D-04
0.12050411D-03	0.29018948D-04	0.77852644D-05	0.35095089D-04	0.66919062D-03	-0.29018822D-04	0.10050120D-03	0.32488749D-04
-0.78385035D-05	-0.70286108D-11	0.68574784D-03	0.77825530D-05	-0.32489155D-04	-0.10417972D-04	0.18415530D-05	-0.14462681D-04
0.20231350D-08	0.29298284D-04	-0.35095128D-04	-0.78388076D-05	-0.18423636D-05	-0.99848921D-05	0.12236227D-08	0.15100685D-04
0.79743497D-09	0.24407891D-04	0.12050526D-03	0.29018711D-04	0.77855963D-05	0.35095721D-04	0.66919172D-03	-0.29018842D-04
0.10050253D-03	0.32489422D-04	-0.78388502D-05	0.40744473D-10	0.68575029D-03	0.77823501D-05	-0.32489891D-04	-0.10418285D-04
0.18415929D-05	-0.14463189D-04	0.43818294D-09	0.29298502D-04	-0.35095883D-04	-0.78385860D-05	-0.18423966D-05	-0.99851905D-05
-0.30122738D-09	0.15101195D-04	0.79341542D-09	0.24408089D-04	0.12050479D-03	0.29018809D-04	0.77854583D-05	0.35095463D-04
0.66918988D-03	-0.29018833D-04	0.10050198D-03	0.32489146D-04	-0.78387061D-05	0.51740621D-10	0.68574748D-03	0.77824352D-05
-0.32489589D-04	-0.10418156D-04	0.18415766D-05	-0.14462788D-04	0.53643651D-09	0.29298227D-04	-0.35095573D-04	-0.78386789D-05
-0.18423831D-05	-0.99850683D-05	-0.20064639D-09	0.15100789D-04	0.79030193D-09	0.24407828D-04	0.12050439D-03	0.29018756D-04
0.77856132D-05	0.35095184D-04	0.66918751D-03	-0.29018948D-04	0.10050153D-03	0.32488903D-04	-0.78388711D-05	0.10124117D-10
0.68574728D-03	0.77822375D-05	-0.32489388D-04	-0.10418061D-04	0.18415663D-05	-0.14463454D-04	0.86470085D-09	0.29298060D-04
-0.35095375D-04	-0.78384692D-05	-0.18423682D-05	-0.99849657D-05	0.10377000D-09	0.15101466D-04	0.79885411D-09	0.24407676D-04
0.12050439D-03	0.29018946D-04	0.77852345D-05	0.35095270D-04	0.66918988D-03	-0.29018776D-04	0.10050153D-03	0.32488920D-04
-0.78384709D-05	-0.31878774D-10	0.68574748D-03	0.77826141D-05	-0.32489315D-04	-0.10418044D-04	0.18415614D-05	-0.14462783D-04
0.12722434D-08	0.29298209D-04	-0.35095289D-04	-0.78388718D-05	-0.18423732D-05	-0.99849657D-05	0.40765418D-09	0.15100791D-04
0.80383476D-09	0.24407828D-04	0.12050479D-03	0.29018822D-04	0.77854332D-05	0.35095469D-04	0.66919172D-03	-0.29018821D-04
0.10050198D-03	0.32489147D-04	-0.78386796D-05	-0.20681772D-10	0.68575029D-03	0.77824602D-05	-0.32489584D-04	-0.10418155D-04
0.18415762D-05	-0.14463185D-04	0.13293194D-08	0.29298490D-04	-0.35095568D-04	-0.78387056D-05	-0.18423834D-05	-0.99850683D-05
0.50851487D-09	0.15101196D-04	0.80259907D-09	0.24408089D-04	0.12050526D-03	0.29018836D-04	0.77853475D-05	0.35095778D-04
0.66919062D-03	-0.29018729D-04	0.10050253D-03	0.32489433D-04	-0.78385873D-05	0.26826920D-10	0.68574784D-03	0.77825975D-05
-0.32489843D-04	-0.10418273D-04	0.18415897D-05	-0.14462682D-04	-0.20142189D-09	0.29298286D-04	-0.35095826D-04	-0.78388504D-05
-0.18423999D-05	-0.99851905D-05	-0.10167024D-08	0.15100685D-04	0.79611715D-09	0.24407891D-04	0.12050411D-03	0.29018804D-04
0.77855518D-05	0.35095023D-04	0.66918944D-03	-0.29018953D-04	0.10050120D-03	0.32488736D-04	-0.78388073D-05	0.25307494D-10
0.68574822D-03	0.77822672D-05	-0.32489210D-04	-0.10417985D-04	0.18415567D-05	-0.14463183D-04	0.19134890D-08	0.29298241D-04
-0.35095193D-04	-0.78385020D-05	-0.18423598D-05	-0.99848921D-05	0.11993319D-08	0.15101189D-04	0.79309534D-09	0.24407842D-04
0.0	0.0	0.0	0.0	0.10000000D+01	-0.29018796D-04	0.10050242D-03	0.32489370D-04
-0.78387193D-05	0.0	0.34287508D-03	0.0	0.0	0.0	0.0	0.0
0.0	0.10000000D+01	-0.35095798D-04	-0.78387070D-05	-0.18423951D-05	-0.99851655D-05	0.0	0.75505494D-05
0.0	0.12204091D-04						

259

ORIGINAL PAGE IS OF POOR QUALITY

STIFK =

0.10000000D+01	0.0	0.48770978D+07	0.0	0.0	0.10000000D+01	0.0	0.23094894D+07
0.0	0.48024904D+07	0.0	0.26359358D+07	0.0	-0.27717367D+07	0.57646505D+08	0.0
-0.45204002D+07	0.0	-0.27772775D+07	0.66828093D+02	0.97543146D+07	0.0	0.26231086D+07	0.0
0.15877452D+07	-0.52512531D+07	0.20332430D+03	0.47369829D+07	0.0	-0.27772881D+07	0.0	-0.12006227D+07
0.11739247D+02	0.46190220D+07	0.17786280D+03	0.96049313D+07	-0.28765171D+08	0.26358911D+07	0.30738528D+07	-0.27717211D+07
0.57646445D+08	-0.26360455D+07	-0.45205273D+07	-0.26233074D+07	-0.27773041D+07	0.19142071D+02	0.97543373D+07	0.30738303D+07
0.26231731D+07	0.10826877D+07	0.15877468D+07	-0.52512348D+07	0.10417311D+03	0.47370016D+07	0.27717252D+07	-0.27773087D+07
-0.15879430D+07	-0.12006119D+07	0.19230026D+02	0.46190043D+07	0.18305862D+03	0.96049556D+07	-0.28764881D+08	0.26360041D+07
0.30738184D+07	-0.27717504D+07	0.57646305D+08	-0.26358646D+07	-0.45203884D+07	-0.26232805D+07	-0.27772724D+07	-0.82135614D+02
0.97542206D+07	0.30738102D+07	0.26230904D+07	0.10826761D+07	0.15877434D+07	-0.52512401D+07	0.20196910D+03	0.47369691D+07
0.27716982D+07	-0.27772887D+07	-0.15879485D+07	-0.12006236D+07	0.38981401D+02	0.46190036D+07	0.19350545D+03	0.96049644D+07
-0.28764999D+08	0.26359567D+07	0.30738325D+07	-0.27717382D+07	0.57646500D+08	-0.26359398D+07	-0.45204453D+07	-0.26232913D+07
-0.27772854D+07	-0.11652526D+03	0.97543523D+07	0.30738183D+07	0.26231245D+07	0.10826809D+07	0.15877448D+07	-0.52512429D+07
0.20444688D+03	0.47370006D+07	0.27717095D+07	-0.27772968D+07	-0.15879462D+07	-0.12006188D+07	0.45176062D+02	0.46190118D+07
0.19624287D+03	0.96049434D+07	-0.28765099D+08	0.26360653D+07	0.30738385D+07	-0.27717562D+07	0.57646648D+08	-0.26358545D+07
-0.45204927D+07	-0.26233283D+07	-0.27772902D+07	-0.31539103D+01	0.97543539D+07	0.30738337D+07	0.26231246D+07	0.10826846D+07
0.15877420D+07	-0.52512723D+07	0.16468836D+03	0.47369802D+07	0.27716904D+07	-0.27773094D+07	-0.15879494D+07	-0.12006148D+07
0.24242517D+02	0.46190418D+07	0.18648272D+03	0.96048994D+07	-0.28765099D+08	0.26358578D+07	0.30738467D+07	-0.27717167D+07
0.57646501D+08	-0.26360622D+07	-0.45204932D+07	-0.26232893D+07	-0.27772988D+07	0.11023260D+03	0.97543529D+07	0.30738218D+07
0.26231645D+07	0.10826849D+07	0.15877476D+07	-0.52512409D+07	0.12447864D+03	0.47370006D+07	0.27717303D+07	-0.27773014D+07
-0.15879423D+07	-0.12006148D+07	0.28127254D+01	0.46190121D+07	0.17344647D+03	0.96049434D+07	-0.28764999D+08	0.26359430D+07
0.30738331D+07	-0.27717356D+07	0.57646306D+08	-0.26359536D+07	-0.45204453D+07	-0.26232887D+07	-0.27772860D+07	0.75835094D+02
0.97542209D+07	0.30738175D+07	0.26231271D+07	0.10826809D+07	0.15877452D+07	-0.52512388D+07	0.12718929D+03	0.47369691D+07
0.27717121D+07	-0.27772963D+07	-0.15879457D+07	-0.12006188D+07	0.92655211D+01	0.46190038D+07	0.17788774D+03	0.96049644D+07
-0.28764881D+08	0.26358678D+07	0.30738238D+07	-0.27717244D+07	0.57646445D+08	-0.26360010D+07	-0.45203887D+07	-0.26232549D+07
-0.27772780D+07	-0.25432229D+02	0.97543373D+07	0.30738024D+07	0.26231165D+07	0.10826763D+07	0.15877470D+07	-0.52512350D+07
0.22467806D+03	0.47370016D+07	0.27717244D+07	-0.27772835D+07	-0.15879438D+07	-0.12006236D+07	0.28677140D+02	0.46190043D+07
0.18609238D+03	0.96049556D+07	-0.28765170D+08	0.26360486D+07	0.30738465D+07	-0.27717512D+07	0.57646504D+08	-0.26358879D+07
-0.45205270D+07	-0.26233370D+07	-0.27772975D+07	-0.73129351D+02	0.97543142D+07	0.30738393D+07	0.26231429D+07	0.10826874D+07
0.15877426D+07	-0.52512545D+07	0.12585655D+03	0.47369828D+07	0.27716949D+07	-0.27773147D+07	-0.15879484D+07	-0.12006119D+07
0.36531157D+02	0.46190218D+07	0.19368435D+03	0.96049313D+07	-0.28764905D+08	0.26359419D+07	0.30738234D+07	-0.27717379D+07
0.57646226D+08	-0.26359326D+07	-0.45204002D+07	-0.26232728D+07	-0.27772772D+07	-0.31488846D+01	0.97541950D+07	0.30738088D+07
0.26231074D+07	0.10826772D+07	0.15877451D+07	-0.52512304D+07	0.16453814D+03	0.47369688D+07	0.27717106D+07	-0.27772884D+07
-0.15879462D+07	-0.12006227D+07	0.24078514D+02	0.46189937D+07	0.18539979D+03	0.96049808D+07	-0.28764905D+08	0.26359358D+07
0.30738236D+07	-0.27717367D+07	0.57646505D+08	-0.26359387D+07	-0.45204002D+07	-0.26232717D+07	-0.27772775D+07	0.66828093D+02
0.97543146D+07	0.30738085D+07	0.26231086D+07	0.10826772D+07	0.15877452D+07	-0.52512531D+07	0.20332430D+03	0.47369829D+07
0.27717118D+07	-0.27772881D+07	-0.15879460D+07	-0.12006227D+07	0.11739247D+02	0.46190220D+07	0.17786280D+03	0.96049313D+07
-0.28765171D+08	0.26358911D+07	0.30738528D+07	-0.27717211D+07	0.57646445D+08	-0.26360455D+07	-0.45205273D+07	-0.26233074D+07
-0.27773041D+07	0.19142071D+02	0.97543373D+07	0.30738303D+07	0.26231731D+07	0.10826877D+07	0.15877468D+07	-0.52512348D+07
0.10417311D+03	0.47370016D+07	0.27717252D+07	-0.27773087D+07	-0.15879430D+07	-0.12006119D+07	0.19230026D+02	0.46190043D+07
0.18305862D+03	0.96049556D+07	-0.28764881D+08	0.26360041D+07	0.30738184D+07	-0.27717504D+07	0.57646305D+08	-0.26358646D+07
-0.45203884D+07	-0.26232805D+07	-0.27772724D+07	-0.82135614D+02	0.97542206D+07	0.30738102D+07	0.26230904D+07	0.10826761D+07
0.15877434D+07	-0.52512401D+07	0.20196910D+03	0.47369691D+07	0.27716982D+07	-0.27772887D+07	-0.15879485D+07	-0.12006236D+07
0.38981401D+02	0.46190036D+07	0.19350545D+03	0.96049644D+07	-0.28764999D+08	0.26359567D+07	0.30738325D+07	-0.27717382D+07
0.57646500D+08	-0.26359398D+07	-0.45204453D+07	-0.26232913D+07	-0.27772854D+07	-0.11652526D+03	0.97543523D+07	0.30738183D+07
0.26231245D+07	0.10826809D+07	0.15877448D+07	-0.52512429D+07	0.20444688D+03	0.47370006D+07	0.27717095D+07	-0.27772968D+07
-0.15879462D+07	-0.12006188D+07	0.45176062D+02	0.46190118D+07	0.19624287D+03	0.96049434D+07	-0.28765099D+08	0.26360653D+07
0.30738385D+07	-0.27717562D+07	0.57646648D+08	-0.26358545D+07	-0.45204927D+07	-0.26233283D+07	-0.27772902D+07	-0.31539103D+01
0.97543539D+07	0.30738337D+07	0.26231246D+07	0.10826846D+07	0.15877420D+07	-0.52512723D+07	0.16468836D+03	0.47369802D+07
0.27716904D+07	-0.27773094D+07	-0.15879494D+07	-0.12006148D+07	0.24242517D+02	0.46190418D+07	0.18648272D+03	0.96048994D+07
-0.28765099D+08	0.26358578D+07	0.30738467D+07	-0.27717167D+07	0.57646501D+08	-0.26360622D+07	-0.45204932D+07	-0.26232893D+07
-0.27772988D+07	0.11023260D+03	0.97543529D+07	0.30738218D+07	0.26231645D+07	0.10826849D+07	0.15877476D+07	-0.52512409D+07
0.12447864D+03	0.47370006D+07	0.27717303D+07	-0.27773014D+07	-0.15879423D+07	-0.12006148D+07	0.28127254D+01	0.46190121D+07
0.17344647D+03	0.96049434D+07	-0.28764999D+08	0.26359430D+07	0.30738331D+07	-0.27717356D+07	0.57646306D+08	-0.26359536D+07
-0.45204453D+07	-0.26232887D+07	-0.27772860D+07	0.75835094D+02	0.97542209D+07	0.30738175D+07	0.26231271D+07	0.10826809D+07
0.15877452D+07	-0.52512388D+07	0.12716929D+03	0.47369691D+07	0.27717121D+07	-0.27772963D+07	-0.15879457D+07	-0.12006188D+07
0.92655211D+01	0.46190038D+07	0.17788774D+03	0.96049644D+07	-0.28764881D+08	0.26358678D+07	0.30738238D+07	-0.27717244D+07
0.57646445D+08	-0.26360010D+07	-0.45203887D+07	-0.26232549D+07	-0.27772780D+07	-0.25432229D+02	0.97543373D+07	0.30738024D+07
0.26231165D+07	0.10826763D+07	0.15877470D+07	-0.52512350D+07	0.22467806D+03	0.47370016D+07	0.27717244D+07	-0.27772835D+07
-0.15879438D+07	-0.12006236D+07	0.28677140D+02	0.46190043D+07	0.18609238D+03	0.96049556D+07	-0.28765170D+08	0.26360486D+07
0.30738465D+07	-0.27717512D+07	0.57646504D+08	-0.26358879D+07	-0.45205270D+07	-0.26233370D+07	-0.27772975D+07	-0.73129351D+02
0.97543142D+07	0.30738393D+07	0.26231429D+07	0.10826874D+07	0.15877426D+07	-0.52512545D+07	0.12585655D+03	0.47369828D+07
0.27716949D+07	-0.27773147D+07	-0.15879484D+07	-0.12006119D+07	0.36531157D+02	0.46190218D+07	0.19368435D+03	0.96049313D+07
0.0	0.0	0.0	0.0	0.10000000D+01	-0.26359326D+07	-0.45204002D+07	-0.26232728D+07
-0.27772772D+07	0.0	0.48770973D+07	0.0	0.0	0.0	0.0	0.0
0.0	0.10000000D+01	0.27717106D+07	-0.27772884D+07	-0.15879462D+07	-0.12006227D+07	0.0	0.23095043D+07
0.0	0.48024904D+07						

HIGHEST NATURAL FREQUENCY (RAD/SEC) = 0.12737131D+07

DELTAT SHOULD BE EQUAL TO OR LESS THAN 0.150000D-05

TIME STEP SIZE USED IN PROGRAM (SEC) = 0.400000D-05

IMPULSE LOADINGS HAVE BEEN SPECIFIED AS DESCRIBED BY INPUT

1 LOCAL INITIAL NORMAL VELOCITY FIELDS ARE DESCRIBED BELOW:

FIRST ELEM	TOTAL ELEMS	WRAD	WRAD1	ANGV1	WRAD2	ANGV2
1	7	-0.100000D+05	-0.100000D+05	0.0	-0.500000D+04	0.200000D+05

THERE IS NO TIME DEPENDENT FORCE DISTRIBUTION DURING THIS RUN

THE FOLLOWING IS THE TIME SOLUTION OF AN EXTERNALLY LOADED STRUCTURE.
OUTPUT WILL BE PRINTED EVERY 10 CYCLES USINGOUTPUT OPTION 3.
REACTION FORCES APPLIED TO THE STRUCTURE WILL BE PRINTED AT EACH OUTPUT CYCLE
FOR NODES AT WHICH BOUNDARY CONDITIONS ARE SPECIFIED. D.O.F. THAT ARE
NOT RESTRAINED AT THAT NODE WILL HAVE A REACTION FORCE = 0.0.

J= 0 TIME (SEC.) = 0.0
WORK INPUT INTO RING (IN.-LB.) = 0.306676D+06
RING KINETIC ENERGY (IN.-LB.) = 0.306676D+06
RING ELASTIC ENERGY (IN.-LB.) = 0.0
RING PLASTIC WORK (IN.-LB.) = 0.0

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN (IN)	STRAIN (OUT)
1	0.0	0.0	0.0	0.0	0.0	0.7700D+01	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.1205D+01	0.7605D+01	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.2379D+01	0.7323D+01	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.3496D+01	0.6861D+01	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.4526D+01	0.6229D+01	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.5445D+01	0.5445D+01	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.6229D+01	0.4526D+01	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.6861D+01	0.3496D+01	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.7323D+01	0.2379D+01	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.7605D+01	0.1205D+01	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.7700D+01	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.7605D+01	-0.1205D+01	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.7323D+01	-0.2379D+01	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.6861D+01	-0.3496D+01	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.6229D+01	-0.4526D+01	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.5445D+01	-0.5445D+01	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.4526D+01	-0.6229D+01	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.3496D+01	-0.6861D+01	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.2379D+01	-0.7323D+01	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.1205D+01	-0.7605D+01	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	-0.7700D+01			0.0	0.0

J= 1 TIME (SEC.) = 0.400000D-05
WORK INPUT INTO RING (IN.-LB.) = 0.306676D+06
RING KINETIC ENERGY (IN.-LB.) = 0.298832D+06
RING ELASTIC ENERGY (IN.-LB.) = 0.181817D+04
RING PLASTIC WORK (IN.-LB.) = 0.602572D+04

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN (IN)	STRAIN (OUT)
1	0.0	-0.3993D-01	0.0	-0.4211D-02	0.0	0.7660D+01	-0.1643D+06	-0.1646D+05	-0.4209D-02	-0.4183D-02
2	-0.5368D-07	-0.3993D-01	0.3806D-06	-0.4211D-02	0.1198D+01	0.7566D+01	-0.1643D+06	-0.1646D+05	-0.4209D-02	-0.4183D-02
3	0.2838D-06	-0.3993D-01	0.5245D-05	-0.4210D-02	0.2367D+01	0.7285D+01	-0.1644D+06	-0.1647D+05	-0.4209D-02	-0.4179D-02
4	0.3751D-05	-0.3993D-01	0.2954D-04	-0.4190D-02	0.3478D+01	0.6825D+01	-0.1651D+06	-0.1654D+05	-0.4191D-02	-0.4152D-02
5	0.2048D-04	-0.3993D-01	0.5958D-04	-0.4057D-02	0.4502D+01	0.6197D+01	-0.1673D+06	-0.1658D+05	-0.4046D-02	-0.4057D-02
6	0.3605D-04	-0.4005D-01	-0.5056D-03	-0.3695D-02	0.5416D+01	0.5416D+01	-0.1639D+06	-0.1453D+05	-0.3511D-02	-0.4219D-02
7	-0.5145D-03	-0.4098D-01	-0.6398D-02	-0.5543D-02	0.6196D+01	0.4502D+01	-0.1780D+06	-0.3129D+05	-0.5832D-02	-0.4533D-02
8	0.1689D-02	-0.1996D-01	0.6158D-01	-0.2106D-02	0.6844D+01	0.3485D+01	0.6358D+05	0.2584D+05	-0.2107D-03	-0.1979D-03
9	-0.5145D-03	0.1046D-02	-0.6399D-02	0.1333D-02	0.7324D+01	0.2380D+01	-0.3253D+03	-0.1914D+04	0.1673D-02	0.3994D-03
10	0.3606D-04	0.1193D-03	-0.5057D-03	-0.5163D-03	0.7605D+01	0.1205D+01	0.3026D+04	0.1301D+03	-0.6995D-03	0.3450D-04
11	0.2049D-04	0.8326D-06	0.5958D-04	-0.1539D-03	0.7700D+01	-0.2049D-04	0.7636D+03	0.8781D+02	-0.1631D-03	-0.1262D-03
12	0.3755D-05	-0.3416D-05	0.2955D-04	-0.2100D-04	0.7605D+01	-0.1205D+01	0.9142D+02	0.1710D+02	-0.1781D-04	-0.3056D-04
13	0.2746D-06	-0.8409D-06	0.5251D-05	-0.3482D-06	0.7323D+01	-0.2379D+01	-0.1292D+01	0.1425D+01	0.6928D-06	-0.3471D-05
14	-0.4825D-07	-0.9731D-07	0.3586D-06	0.5535D-06	0.6861D+01	-0.3496D+01	-0.3079D+01	-0.1780D+00	0.7055D-06	0.9759D-07
15	-0.1985D-07	0.2247D-08	-0.7353D-07	0.1428D-06	0.6229D+01	-0.4526D+01	-0.6964D+00	-0.8572D-01	0.1475D-06	0.1285D-06
16	-0.3279D-08	0.3487D-08	-0.2843D-07	0.1732D-07	0.5445D+01	-0.5445D+01	-0.7299D-01	-0.1508D-01	0.1385D-07	0.2774D-07
17	-0.1815D-09	0.7647D-09	-0.4563D-08	-0.1898D-09	0.4526D+01	-0.6229D+01	0.3674D-02	-0.1003D-02	-0.1163D-08	0.2731D-08
18	0.5604D-10	0.7697D-10	-0.2279D-09	-0.5705D-09	0.3496D+01	-0.6861D+01	0.3090D-02	0.2174D-03	-0.6977D-09	-0.1887D-09
19	0.1890D-10	-0.4788D-11	0.8395D-10	-0.1304D-09	0.2379D+01	-0.7323D+01	0.6237D-03	0.8210D-04	-0.1313D-09	-0.1277D-09
20	0.2874D-11	-0.3537D-11	0.2683D-10	-0.1331D-10	0.1205D+01	-0.7605D+01	0.5042D-04	0.1371D-04	-0.9559D-11	-0.2456D-10
21	0.0	-0.1371D-11	0.0	0.1281D-11	0.9564D-27	-0.7700D+01			0.3076D-11	-0.4105D-11

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ORIGINAL PAGE IS
OF POOR QUALITY

CYCLE= 10

ELEMENT	SI STA 1	SO STA 1	SI STA 2	SO STA 2	SI STA 3	SO STA 3
1	-0.46634614D-01	-0.46613764D-01	-0.47142843D-01	-0.47159117D-01	-0.46585892D-01	-0.46571031D-01
	-0.46624189D-01	0.0	-0.47150980D-01	0.0	-0.46578462D-01	0.0
2	-0.46575659D-01	-0.46516657D-01	-0.47014564D-01	-0.46995446D-01	-0.46320722D-01	-0.46269391D-01
	-0.46546158D-01	0.0	-0.47005005D-01	0.0	-0.46295056D-01	0.0
3	-0.46119769D-01	-0.46284822D-01	-0.46372676D-01	-0.46313018D-01	-0.45501150D-01	-0.45145198D-01
	-0.46202296D-01	0.0	-0.46342847D-01	0.0	-0.45323174D-01	0.0
4	-0.45450041D-01	-0.43894255D-01	-0.44040502D-01	-0.44308822D-01	-0.40354253D-01	-0.42313584D-01
	-0.44672148D-01	0.0	-0.44174662D-01	0.0	-0.41333919D-01	0.0
5	-0.37503299D-01	-0.43283765D-01	-0.40204692D-01	-0.32400894D-01	-0.44979619D-01	-0.23674817D-01
	-0.40393532D-01	0.0	-0.36302793D-01	0.0	-0.34327218D-01	0.0
6	-0.42209898D-01	-0.13308385D-01	-0.15899850D-01	-0.33372985D-01	0.66870863D-02	-0.57371533D-01
	-0.27759142D-01	0.0	-0.24636418D-01	0.0	-0.25342223D-01	0.0
7	0.22581255D-01	-0.91441771D-01	0.14859183D-01	-0.62925638D-01	-0.95308597D-04	-0.42393676D-01
	-0.34430258D-01	0.0	-0.24033228D-01	0.0	-0.21244592D-01	0.0
8	-0.39755521D-01	0.33611922D-01	-0.51132627D-01	0.21152513D-01	-0.49288907D-01	0.22514232D-01
	-0.30717994D-02	0.0	-0.14990057D-01	0.0	-0.13387338D-01	0.0
9	-0.34901547D-01	0.88546734D-02	-0.17362076D-01	0.52177394D-02	-0.49493983D-02	-0.37729692D-02
	-0.13023437D-01	0.0	-0.60721682D-02	0.0	-0.43611837D-02	0.0
10	-0.29612027D-02	-0.43640668D-02	-0.62842597D-03	-0.65670637D-02	0.18877811D-02	-0.84918704D-02
	-0.36126345D-02	0.0	-0.35977448D-02	0.0	-0.33020447D-02	0.0
11	0.14071050D-02	-0.72089070D-02	-0.16874755D-02	-0.36032318D-02	-0.44212693D-02	0.37686682D-03
	-0.23009010D-02	0.0	-0.26453536D-02	0.0	-0.20222012D-02	0.0
12	-0.40988190D-02	0.35286220D-03	-0.17141995D-02	-0.70323277D-03	0.31252491D-03	-0.21318534D-02
	-0.18729784D-02	0.0	-0.12087162D-02	0.0	-0.90966424D-03	0.0
13	0.27472065D-03	-0.12733659D-02	-0.28317293D-03	-0.52871344D-03	-0.63732977D-03	0.42959810D-03
	-0.49932260D-03	0.0	-0.40594319D-03	0.0	-0.10386583D-03	0.0
14	-0.28390311D-03	-0.98555975D-04	0.32788711D-04	-0.37737806D-04	0.14493651D-03	-0.19249817D-03
	-0.19122954D-03	0.0	-0.24745475D-05	0.0	-0.23780831D-04	0.0
15	0.67823581D-05	0.78616708D-04	-0.98493671D-05	0.45606296D-04	0.10317334D-04	0.51537013D-04
	0.42699533D-04	0.0	0.17878464D-04	0.0	0.30927174D-04	0.0
16	0.38266155D-04	0.56658968D-05	0.24039983D-04	0.13756723D-04	0.85630887D-05	0.20488374D-04
	0.21966026D-04	0.0	0.18898353D-04	0.0	0.14525731D-04	0.0
17	0.72221632D-05	0.12267237D-04	0.78487827D-05	0.86620228D-05	0.64620549D-05	0.29389299D-05
	0.97446999D-05	0.0	0.82554027D-05	0.0	0.47004924D-05	0.0
18	0.34974086D-05	0.50564479D-05	0.20585962D-05	0.29008742D-05	0.15167993D-05	0.16922162D-05
	0.42769282D-05	0.0	0.24797352D-05	0.0	0.16045077D-05	0.0
19	0.13418098D-05	0.11919649D-05	0.70964630D-06	0.73666326D-06	0.36257670D-06	0.58143097D-06
	0.12668873D-05	0.0	0.72315478D-06	0.0	0.47200384D-06	0.0
20	0.34471418D-06	0.33325813D-06	0.23418164D-06	0.24091080D-06	0.17328668D-06	0.20079319D-06
	0.33898615D-06	0.0	0.23754622D-06	0.0	0.18703993D-06	0.0

CYCLE= 10

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	0.21954989D-06	0.22984242D-06	0.21954986D-06	0.22984239D-06
	0.22469615D-06	0.0		

J= 10 TIME (SEC.) = 0.400000D-04
WORK INPUT INTO RING (IN.-LB.) = 0.306676D+06
RING KINETIC ENERGY (IN.-LB.) = 0.222548D+06
RING ELASTIC ENERGY (IN.-LB.) = 0.579372D+04
RING PLASTIC WORK (IN.-LB.) = 0.783343D+05

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN (IN)	STRAIN (OUT)
1	0.0	-0.3701D+00	0.0	-0.4740D-01	0.0	0.7330D+01	-0.2841D+06	-0.2841D+05	-0.4628D-01	-0.4626D-01
2	0.8171D-04	-0.3701D+00	-0.8125D-05	-0.4733D-01	0.1147D+01	0.7240D+01	-0.2835D+06	-0.2835D+05	-0.4622D-01	-0.4619D-01
3	0.3655D-03	-0.3702D+00	-0.1265D-03	-0.4699D-01	0.2265D+01	0.6971D+01	-0.2811D+06	-0.2808D+05	-0.4588D-01	-0.4591D-01
4	0.1475D-02	-0.3701D+00	-0.3670D-03	-0.4598D-01	0.3329D+01	0.6530D+01	-0.2732D+06	-0.2742D+05	-0.4508D-01	-0.4444D-01
5	0.5936D-02	-0.3710D+00	0.3325D-03	-0.4025D-01	0.4313D+01	0.5926D+01	-0.2479D+06	-0.2337D+05	-0.3868D-01	-0.4172D-01
6	0.1601D-01	-0.3725D+00	-0.2319D-01	-0.4162D-01	0.5193D+01	0.5170D+01	-0.1873D+06	-0.2655D+05	-0.4471D-01	-0.2782D-01
7	0.5080D-01	-0.4004D+00	0.2982D-01	-0.5958D-02	0.5935D+01	0.4249D+01	-0.1541D+06	-0.3039D+05	0.7152D-02	-0.4344D-01
8	0.7131D-01	-0.1827D+00	0.2657D+00	-0.5213D-01	0.6730D+01	0.3349D+01	-0.1428D+06	0.4116D+02	-0.1809D-01	-0.7670D-02
9	0.2729D-01	0.1327D-01	0.4657D-01	-0.2985D-01	0.7344D+01	0.2358D+01	-0.1135D+06	0.1776D+04	-0.3592D-01	-0.5509D-02
10	0.7713D-02	0.1401D-01	-0.2151D-01	-0.3807D-02	0.7620D+01	0.1199D+01	-0.1019D+06	-0.1547D+05	-0.3237D-02	-0.4564D-02
11	0.4562D-02	-0.3772D-02	-0.3550D-02	-0.1859D-03	0.7696D+01	-0.4562D-02	-0.7675D+05	-0.9528D+04	0.1210D-02	-0.4349D-02
12	0.2329D-02	0.1313D-02	0.2231D-02	-0.3538D-02	0.7606D+01	-0.1207D+01	-0.3507D+05	-0.2529D+04	-0.4292D-02	-0.1240D-02
13	0.3102D-03	-0.3947D-03	-0.8133D-03	0.7696D-05	0.7323D+01	-0.2380D+01	-0.1178D+05	-0.1415D+04	0.3441D-03	-0.1000D-02
14	-0.5350D-05	0.1253D-03	-0.7915D-04	-0.3528D-03	0.6967D+01	-0.3496D+01	-0.7180D+02	-0.7539D+02	-0.4596D-03	-0.3244D-04
15	-0.5894D-04	-0.5319D-04	0.1434D-03	0.3762D-04	0.6229D+01	-0.4526D+01	0.5187D+03	0.1055D+03	0.5889D-04	-0.2616D-04
16	-0.3986D-04	-0.1891D-05	-0.2611D-04	0.3263D-04	0.5445D+01	-0.5445D+01	0.5483D+03	0.4489D+02	0.3273D-04	0.3232D-04
17	-0.1356D-04	-0.8980D-06	0.5077D-05	0.8183D-05	0.4526D+01	-0.6229D+01	0.2395D+03	0.2474D+02	0.6644D-05	0.1280D-04
18	-0.4382D-05	-0.9140D-06	0.2706D-05	0.4522D-05	0.3496D+01	-0.6861D+01	0.7195D+02	0.8009D+01	0.4712D-05	0.3955D-05
19	-0.1283D-05	-0.1475D-06	0.1168D-06	0.1532D-05	0.2379D+01	-0.7323D+01	0.2098D+02	0.2124D+01	0.1545D-05	0.1493D-05
20	-0.3057D-06	-0.2456D-07	0.2252D-07	0.3824D-06	0.1205D+01	-0.7605D+01	0.6892D+01	0.6957D+00	0.3661D-06	0.4314D-06
21	0.0	-0.1628D-07	0.0	0.1732D-06	0.1136D-22	-0.7700D+01			0.1689D-06	0.1859D-06

REACTIONS AT NODE	RV (LBS)	RW (LBS)	RM (IN-LBS)
1	0.270320D+06	0.0	-0.284250D+05
21	0.541103D+01	0.0	-0.594910D+00

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.406287D-01	8	2	1	0.120000D-04
INTERFACE	0.981461D-02	8	1	1	0.800000D-05

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.229842D-06	20	1	0.400000D-04	2
INTERFACE	0.224696D-06	20	1	0.400000D-04	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.715155D-02	7	1	0.400000D-04

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ORIGINAL PAGE IS
OF POOR QUALITY

CYCLE= 20

ELEMENT	STA 1 SI	STA 1 SO	STA 2 SI	STA 2 SO	STA 3 SI	STA 3 SO
1	-0.81080454D-01	-0.80895465D-01	-0.81187515D-01	-0.81005996D-01	-0.80334731D-01	-0.80084296D-01
	-0.80987960D-01	0.0	-0.81096756D-01	0.0	-0.80209514D-01	0.0
2	-0.79813357D-01	-0.79715948D-01	-0.78996336D-01	-0.78663052D-01	-0.77091188D-01	-0.76442452D-01
	-0.79764652D-01	0.0	-0.78829694D-01	0.0	-0.76766820D-01	0.0
3	-0.76303527D-01	-0.74114293D-01	-0.73243837D-01	-0.72168329D-01	-0.67897544D-01	-0.67787632D-01
	-0.75208910D-01	0.0	-0.72706083D-01	0.0	-0.67842588D-01	0.0
4	-0.62612557D-01	-0.69530308D-01	-0.60643927D-01	-0.58418114D-01	-0.61011188D-01	-0.49754895D-01
	-0.66071433D-01	0.0	-0.59531021D-01	0.0	-0.55383041D-01	0.0
5	-0.61931917D-01	-0.40830132D-01	-0.58736583D-01	-0.31391833D-01	-0.55978837D-01	-0.22390256D-01
	-0.51376025D-01	0.0	-0.45064208D-01	0.0	-0.39184546D-01	0.0
6	-0.41269730D-01	-0.23946742D-01	-0.21283657D-02	-0.74503881D-01	0.29433635D-01	-0.13345526D+00
	-0.32608236D-01	0.0	-0.38316124D-01	0.0	-0.52010812D-01	0.0
7	0.33695275D-01	-0.12893628D+00	0.20067750D-01	-0.80856344D-01	-0.96911016D-03	-0.40548297D-01
	-0.47620501D-01	0.0	-0.30394297D-01	0.0	-0.20758704D-01	0.0
8	-0.44718751D-01	0.35183113D-01	-0.70473313D-01	0.29917600D-01	-0.84231940D-01	0.37323927D-01
	-0.47678187D-02	0.0	-0.20277857D-01	0.0	-0.23454006D-01	0.0
9	-0.71779001D-01	0.24695457D-01	-0.40882846D-01	0.15008264D-01	-0.12514042D-01	0.25751123D-02
	-0.23541772D-01	0.0	-0.12937291D-01	0.0	-0.49694647D-02	0.0
10	-0.54619320D-02	-0.63957111D-03	-0.27823113D-02	-0.42224333D-02	0.85429322D-04	-0.75949071D-02
	-0.30507515D-02	0.0	-0.35023723D-02	0.0	-0.37547389D-02	0.0
11	0.14364349D-02	-0.97396986D-02	0.13487222D-02	-0.90351700D-02	0.14642824D-02	-0.81640327D-02
	-0.41516319D-02	0.0	-0.38432239D-02	0.0	-0.33498751D-02	0.0
12	0.60067351D-03	-0.67252753D-02	-0.17672949D-02	-0.45446274D-02	-0.42196659D-02	-0.24631581D-02
	-0.30623009D-02	0.0	-0.31559612D-02	0.0	-0.33414120D-02	0.0
13	-0.52800685D-02	-0.12641106D-02	-0.51357179D-02	-0.15853762D-02	-0.46970837D-02	-0.15835271D-02
	-0.32720895D-02	0.0	-0.33605471D-02	0.0	-0.31403054D-02	0.0
14	-0.35734482D-02	-0.31406366D-02	-0.22882336D-02	-0.41320302D-02	-0.13357963D-02	-0.54793196D-02
	-0.33570424D-02	0.0	-0.32101319D-02	0.0	-0.34075579D-02	0.0
15	-0.19832852D-02	-0.44870937D-02	-0.32978024D-02	-0.35473561D-02	-0.42576939D-02	-0.22347263D-02
	-0.32351895D-02	0.0	-0.34225793D-02	0.0	-0.32462101D-02	0.0
16	-0.38295540D-02	-0.28756242D-02	-0.28775022D-02	-0.31985274D-02	-0.20972479D-02	-0.37027118D-02
	-0.33525891D-02	0.0	-0.30380148D-02	0.0	-0.28999798D-02	0.0
17	-0.22059096D-02	-0.30016456D-02	-0.22843195D-02	-0.24859155D-02	-0.21774574D-02	-0.17754695D-02
	-0.26037771D-02	0.0	-0.23851175D-02	0.0	-0.19764635D-02	0.0
18	-0.18009630D-02	-0.19066662D-02	-0.13533700D-02	-0.15810460D-02	-0.10239293D-02	-0.13803848D-02
	-0.19539146D-02	0.0	-0.14672080D-02	0.0	-0.12021570D-02	0.0
19	-0.96941440D-03	-0.10445055D-02	-0.78084623D-03	-0.82023571D-03	-0.60381419D-03	-0.60810834D-03
	-0.10069599D-02	0.0	-0.80054097D-03	0.0	-0.60596127D-03	0.0
20	-0.49164729D-03	-0.58345161D-03	-0.40551769D-03	-0.46548608D-03	-0.38019815D-03	-0.41167543D-03
	-0.53754945D-03	0.0	-0.43550188D-03	0.0	-0.39593679D-03	0.0

CYCLE= 20

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.39638247D-03	-0.45095377D-03	-0.39646106D-03	-0.45105549D-03
	-0.42366812D-03	0.0		

J= 20 TIME (SEC.) = 0.800000D-04
WORK INPUT INTO RING (IN.-LB.) = 0.306676D+06
RING KINETIC ENERGY (IN.-LB.) = 0.170015D+06
RING ELASTIC ENERGY (IN.-LB.) = 0.608105D+04
RING PLASTIC WORK (IN.-LB.) = 0.130581D+06

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN (IN)	STRAIN (OUT)
1	0.0	-0.6654D+00	0.0	-0.8438D-01	0.0	0.7035D+01	-0.2923D+06	-0.2922D+05	-0.8084D-01	-0.8074D-01
2	0.2410D-02	-0.6656D+00	-0.6097D-03	-0.8330D-01	0.1103D+01	0.6947D+01	-0.2869D+06	-0.2863D+05	-0.7986D-01	-0.7977D-01
3	0.7854D-02	-0.6660D+00	-0.1684D-02	-0.7929D-01	0.2181D+01	0.6687D+01	-0.2718D+06	-0.2723D+05	-0.7635D-01	-0.7553D-01
4	0.2175D-01	-0.6688D+00	-0.5061D-02	-0.6827D-01	0.3211D+01	0.6255D+01	-0.2314D+06	-0.2049D+05	-0.6532D-01	-0.6776D-01
5	0.5069D-01	-0.6662D+00	-0.1170D-01	-0.6002D-01	0.4175D+01	0.5661D+01	-0.2098D+06	-0.1621D+05	-0.6022D-01	-0.5193D-01
6	0.9136D-01	-0.7145D+00	-0.9439D-01	-0.5217D-01	0.5004D+01	0.4875D+01	-0.1690D+06	-0.3297D+05	-0.5128D-01	-0.3161D-01
7	0.1782D+00	-0.7464D+00	0.1251D+00	-0.1177D-01	0.5730D+01	0.3943D+01	-0.1358D+06	-0.2999D+05	0.1926D-01	-0.7325D-01
8	0.1898D+00	-0.3304D+00	0.4306D+00	-0.1170D+00	0.6653D+01	0.3177D+01	-0.1092D+06	0.7474D+04	-0.2070D-01	-0.7629D-02
9	0.9476D-01	0.4515D-01	0.1265D+00	-0.6282D-01	0.7395D+01	0.2303D+01	-0.1010D+06	0.7377D+04	-0.6760D-01	-0.8583D-02
10	0.4683D-01	0.7430D-01	-0.4233D-01	-0.5518D-02	0.7686D+01	0.1170D+01	-0.9310D+05	-0.9434D+04	-0.5221D-02	-0.2765D-02
11	0.3399D-01	0.2700D-01	-0.3799D-01	-0.2064D-02	0.7727D+01	-0.3399D-01	-0.8861D+05	-0.1556D+05	-0.3340D-04	-0.5260D-02
12	0.3013D-01	0.5634D-02	-0.6563D-02	-0.8525D-03	0.7606D+01	-0.1235D+01	-0.9132D+05	-0.1185D+05	0.2987D-03	-0.4218D-02
13	0.2595D-01	0.1083D-01	0.1848D-02	-0.4242D-02	0.7325D+01	-0.2407D+01	-0.9540D+05	-0.6498D+04	-0.4683D-02	-0.2876D-02
14	0.1909D-01	0.9726D-02	-0.8912D-02	-0.3809D-02	0.6861D+01	-0.3517D+01	-0.9314D+05	-0.1110D+05	-0.4017D-02	-0.2997D-02
15	0.1467D-01	0.3143D-02	-0.3317D-02	-0.2307D-02	0.6223D+01	-0.4540D+01	-0.9930D+05	-0.1017D+05	-0.1800D-02	-0.3793D-02
16	0.1022D-01	0.3338D-02	-0.2578D-02	-0.3832D-02	0.5440D+01	-0.5454D+01	-0.8815D+05	-0.9125D+04	-0.4072D-02	-0.3069D-02
17	0.6231D-02	0.1069D-02	-0.1600D-02	-0.2388D-02	0.4522D+01	-0.6234D+01	-0.6920D+05	-0.7115D+04	-0.2200D-02	-0.2937D-02
18	0.3330D-02	0.7130D-03	-0.9979D-03	-0.1975D-02	0.3493D+01	-0.6863D+01	-0.4257D+05	-0.4477D+04	-0.2004D-02	-0.1877D-02
19	0.1518D-02	0.1921D-03	-0.3038D-03	-0.1048D-02	0.2370D+01	-0.7324D+01	-0.2323D+05	-0.2361D+04	-0.1018D-02	-0.1138D-02
20	0.5361D-03	0.7818D-04	-0.1841D-03	-0.5534D-03	0.1204D+01	-0.7605D+01	-0.1264D+05	-0.1322D+04	-0.5473D-03	-0.5713D-03
21	0.0	0.2999D-04	0.0	-0.3906D-03	-0.2092D-19	-0.7700D+01			-0.3875D-03	-0.3994D-03

REACTIONS AT NODE	RV (LBS)	RW (LBS)	RM (IN-LBS)
1	0.268202D+06	0.0	-0.293358D+05
21	-0.114003D+05	0.0	0.115324D+04

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.406287D-01	8	2	1	0.120000D-04
INTERFACE	0.981461D-02	8	1	1	0.800000D-05

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.104085D-04	20	1	0.600000D-04	2
INTERFACE	0.100070D-04	20	1	0.600000D-04	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.192603D-01	7	1	0.800000D-04

CYCLE= 30

ELEMENT	STA 1 SI	STA 1 SO	STA 2 SI	STA 2 SO	STA 3 SI	STA 3 SO
1	-0.97555692D-01	-0.96552079D-01	-0.97073742D-01	-0.95689131D-01	-0.95514855D-01	-0.93661353D-01
	-0.97053886D-01	0.0	-0.96381437D-01	0.0	-0.94588104D-01	0.0
2	-0.94133282D-01	-0.92340899D-01	-0.90732847D-01	-0.88369775D-01	-0.85456571D-01	-0.82388530D-01
	-0.93237091D-01	0.0	-0.89551311D-01	0.0	-0.83922551D-01	0.0
3	-0.90809512D-01	-0.83951327D-01	-0.76250112D-01	-0.76940728D-01	-0.69900004D-01	-0.68028140D-01
	-0.82380420D-01	0.0	-0.76595420D-01	0.0	-0.68964072D-01	0.0
4	-0.66636468D-01	-0.64999551D-01	-0.69967367D-01	-0.50054490D-01	-0.75961044D-01	-0.37898474D-01
	-0.65818009D-01	0.0	-0.60010928D-01	0.0	-0.56929759D-01	0.0
5	-0.73405476D-01	-0.32313698D-01	-0.60982291D-01	-0.25036768D-01	-0.53706724D-01	-0.23106931D-01
	-0.52859587D-01	0.0	-0.43009530D-01	0.0	-0.38406827D-01	0.0
6	-0.28791290D-01	-0.32373654D-01	0.24171667D-01	-0.10760661D+00	0.67884410D-01	-0.19384841D+00
	-0.30582472D-01	0.0	-0.41717474D-01	0.0	-0.62981998D-01	0.0
7	0.59321800D-01	-0.14753360D+00	0.31264575D-01	-0.91063594D-01	0.96377634D-03	-0.36251783D-01
	-0.44105900D-01	0.0	-0.29899509D-01	0.0	-0.17644003D-01	0.0
8	-0.45256824D-01	0.38798837D-01	-0.81476834D-01	0.44819295D-01	-0.10800423D+00	0.61468115D-01
	-0.32289937D-02	0.0	-0.18328769D-01	0.0	-0.23268059D-01	0.0
9	-0.98715917D-01	0.53473210D-01	-0.56523830D-01	0.32707493D-01	-0.16310429D-01	0.94164082D-02
	-0.22621354D-01	0.0	-0.11908168D-01	0.0	-0.34470103D-02	0.0
10	-0.72647136D-02	0.42747826D-02	-0.26144610D-02	0.17120284D-03	0.13104064D-02	-0.46471618D-02
	-0.14949655D-02	0.0	-0.12216291D-02	0.0	-0.16683777D-02	0.0
11	0.30519087D-02	-0.70593215D-02	0.43467443D-02	-0.80156171D-02	0.57045721D-02	-0.89556736D-02
	-0.20037064D-02	0.0	-0.18344364D-02	0.0	-0.16255507D-02	0.0
12	0.51439265D-02	-0.72473501D-02	0.34055408D-02	-0.53706666D-02	0.15204741D-02	-0.36905482D-02
	-0.10517118D-02	0.0	-0.98256291D-03	0.0	-0.10850371D-02	0.0
13	0.44240285D-03	-0.26683475D-02	-0.76258876D-03	-0.14258231D-02	-0.20709706D-02	-0.29484403D-03
	-0.11129724D-02	0.0	-0.10942059D-02	0.0	-0.11829073D-02	0.0
14	-0.27116152D-02	0.37066407D-03	-0.30002787D-02	0.37176259D-03	-0.32889902D-02	0.38486891D-03
	-0.11704756D-02	0.0	-0.13142581D-02	0.0	-0.14520607D-02	0.0
15	-0.28747464D-02	-0.14559113D-03	-0.13483725D-02	-0.18672807D-02	0.16987415D-03	-0.35962625D-02
	-0.15101688D-02	0.0	-0.16078266D-02	0.0	-0.17131942D-02	0.0
16	0.52151004D-03	-0.43518235D-02	-0.65651349D-03	-0.34703982D-02	-0.21088716D-02	-0.28894181D-02
	-0.19151567D-02	0.0	-0.20634559D-02	0.0	-0.24991448D-02	0.0
17	-0.32450642D-02	-0.16706979D-02	-0.36368039D-02	-0.22525167D-02	-0.36633261D-02	-0.24440985D-02
	-0.24578810D-02	0.0	-0.29446603D-02	0.0	-0.30537123D-02	0.0
18	-0.30467136D-02	-0.38816992D-02	-0.28380060D-02	-0.43534353D-02	-0.27999830D-02	-0.50098371D-02
	-0.34642064D-02	0.0	-0.35957207D-02	0.0	-0.39049101D-02	0.0
19	-0.35983277D-02	-0.44146873D-02	-0.45573574D-02	-0.48952437D-02	-0.48043412D-02	-0.46265402D-02
	-0.40065075D-02	0.0	-0.47263006D-02	0.0	-0.47154407D-02	0.0
20	-0.47144183D-02	-0.45324474D-02	-0.45593546D-02	-0.52175168D-02	-0.44172933D-02	-0.59177751D-02
	-0.46234329D-02	0.0	-0.48884357D-02	0.0	-0.51675342D-02	0.0

CYCLE= 30

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.45345178D-02	-0.53447584D-02	-0.45448457D-02	-0.53591185D-02
	-0.49396381D-02	0.0		

264

J= 30 TIME (SEC.) = 0.120000D-03

WORK INPUT INTO RING (IN.-LB.) = 0.306676D+06
RING KINETIC ENERGY (IN.-LB.) = 0.150824D+06
RING PLASTIC ENERGY (IN.-LB.) = 0.439917D+04
RING PLASTIC WORK (IN.-LB.) = 0.151453D+06

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	-0.8863D+00	0.0	-0.1025D+00	0.0	0.6814D+01	-0.2012D+06	-0.1978D+05	-0.9738D-01	-0.9692D-01
2	0.1640D-01	-0.8873D+00	-0.4261D-02	-0.9930D-01	0.1082D+01	0.6726D+01	-0.2256D+06	-0.2126D+05	-0.9459D-01	-0.9367D-01
3	0.4230D-01	-0.8920D+00	-0.1152D-01	-0.8655D-01	0.2144D+01	0.6462D+01	-0.1718D+06	-0.1462D+05	-0.8271D-01	-0.8284D-01
4	0.8694D-01	-0.8928D+00	-0.9524D-02	-0.6953D-01	0.3168D+01	0.6026D+01	-0.1410D+06	-0.4159D+04	-0.6700D-01	-0.6727D-01
5	0.1445D+00	-0.9082D+00	-0.6963D-01	-0.7231D-01	0.4109D+01	0.5410D+01	-0.9916D+05	-0.2811D+04	-0.7264D-01	-0.5117D-01
6	0.2190D+00	-0.1034D+01	-0.1782D+00	-0.6324D-03	0.4868D+01	0.4559D+01	-0.8793D+05	-0.3078D+05	-0.4927D-01	-0.3367D-01
7	0.3639D+00	-0.1065D+01	0.2218D+00	-0.6238D-02	0.5582D+01	0.3606D+01	-0.8459D+05	-0.2742D+05	0.5158D-01	-0.8123D-01
8	0.3412D+00	-0.4462D+00	0.5912D+00	-0.2155D+00	0.6618D+01	0.2989D+01	-0.4230D+05	0.1603D+05	-0.2123D-01	-0.6332D-02
9	0.1702D+00	0.1104D+00	0.2085D+00	-0.9090D-01	0.7481D+01	0.2252D+01	-0.4068D+05	0.1695D+05	-0.8707D-01	0.1086D-02
10	0.9589D-01	0.1696D+00	-0.6084D-01	-0.7170D-02	0.7788D+01	0.1136D+01	-0.2693D+05	0.1271D+04	-0.6620D-02	-0.1312D-02
11	0.6916D-01	0.9680D-01	-0.6927D-01	-0.2119D-02	0.7797D+01	-0.6916D-01	-0.2371D+05	-0.1028D+05	0.1405D-02	-0.3086D-02
12	0.5852D-01	0.4371D-01	-0.3185D-01	0.1809D-02	0.7639D+01	-0.1269D+01	-0.2554D+05	-0.1057D+05	0.4117D-02	-0.3080D-02
13	0.5413D-01	0.3294D-01	-0.5274D-02	-0.1689D-03	0.7338D+01	-0.2441D+01	-0.2964D+05	-0.3997D+04	0.3454D-03	-0.1656D-02
14	0.4744D-01	0.3772D-01	-0.3262D-02	-0.1882D-02	0.6873D+01	-0.3555D+01	-0.3813D+05	-0.5520D+03	-0.2218D-02	-0.8466D-03
15	0.3892D-01	0.3462D-01	-0.1347D-01	-0.2528D-02	0.6235D+01	-0.4578D+01	-0.4665D+05	-0.5167D+04	-0.2899D-02	-0.1040D-02
16	0.3254D-01	0.2228D-01	-0.[illegible]90D-01	-0.6019D-03	0.5437D+01	-0.5483D+01	-0.5987D+05	-0.8708D+04	0.1058D-03	-0.2441D-02
17	0.2762D-01	0.1940D-01	-0.3370D-02	-0.2665D-02	0.4515D+01	-0.6261D+01	-0.8544D+05	-0.7205D+04	-0.2745D-02	-0.2385D-02
18	0.2084D-01	0.1645D-01	-0.7577D-02	-0.3341D-02	0.3485D+01	-0.6885D+01	-0.1043D+06	-0.1190D+05	-0.3340D-02	-0.3206D-02
19	0.1467D-01	0.1231D-01	-0.2982D-02	-0.3427D-02	0.2369D+01	-0.7339D+01	-0.1284D+06	-0.1265D+05	-0.3207D-02	-0.4048D-02
20	0.7414D-02	0.1144D-01	-0.1992D-02	-0.4677D-02	0.1199D+01	-0.7618D+01	-0.1381D+06	-0.1401D+05	-0.4712D-02	-0.4522D-02
21	0.0	0.1016D-01	0.0	-0.4818D-02	-0.7087D-17	-0.7710D+01			-0.4588D-02	-0.5461D-02

REACTIONS AT NODE	RV (LBS)	RW (LBS)	RM (IN-LBS)
1	0.196612D+06	0.0	-0.203165D+05
21	-0.135747D+06	0.0	0.138456D+05

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.678844D-01	6	1	3	0.120000D-03
INTERFACE	0.981461D-02	8	1	1	0.800000D-05

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.104085D-04	20	1	0.600000D-04	2
INTERFACE	0.100070D-04	20	1	0.600000D-04	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.515788D-01	7	1	0.120000D-03

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CYCLE= 40

ELEMENT	SI (STA 1)	SO (STA 1)	SI (STA 2)	SO (STA 2)	SI (STA 3)	SO (STA 3)
1	-0.92135959D-01	-0.86002837D-01	-0.90742796D-01	-0.86670923D-01	-0.86145249D-01	-0.83915597D-01
	-0.89069398D-01	0.0	-0.88706859D-01	0.0	-0.85030423D-01	0.0
2	-0.82944943D-01	-0.84307207D-01	-0.81320719D-01	-0.79598871D-01	-0.78606514D-01	-0.73718428D-01
	-0.83626075D-01	0.0	-0.80459795D-01	0.0	-0.76162471D-01	0.0
3	-0.76723873D-01	-0.72635480D-01	-0.75039417D-01	-0.65436819D-01	-0.71285235D-01	-0.56018659D-01
	-0.74679677D-01	0.0	-0.70238118D-01	0.0	-0.63651947D-01	0.0
4	-0.69879207D-01	-0.50037764D-01	-0.72608463D-01	-0.37534311D-01	-0.76453535D-01	-0.26251601D-01
	-0.59958485D-01	0.0	-0.55071387D-01	0.0	-0.51352568D-01	0.0
5	-0.70208085D-01	-0.28003478D-01	-0.54873814D-01	-0.24775576D-01	-0.43825832D-01	-0.25855703D-01
	-0.49105782D-01	0.0	-0.39824695D-01	0.0	-0.34840767D-01	0.0
6	-0.69324253D-02	-0.44910292D-01	0.52351595D-01	-0.12734017D+00	0.97020874D-01	-0.22677722D+00
	-0.25921358D-01	0.0	-0.37494288D-01	0.0	-0.64478173D-01	0.0
7	0.79801521D-01	-0.15606459D+00	0.42436099D-01	-0.97309863D-01	0.49950315D-02	-0.37632539D-01
	-0.38131537D-01	0.0	-0.27436882D-01	0.0	-0.16318754D-01	0.0
8	-0.43814659D-01	0.39275414D-01	-0.85939980D-01	0.55190700D-01	-0.12153312D+00	0.78905838D-01
	-0.22696221D-02	0.0	-0.15374640D-01	0.0	-0.21313642D-01	0.0
9	-0.11952015D+00	0.81866893D-01	-0.70472372D-01	0.50132303D-01	-0.20988325D-01	0.17802851D-01
	-0.18826630D-01	0.0	-0.10170035D-01	0.0	-0.15927368D-02	0.0
10	-0.10624013D-01	0.83882525D-02	-0.51232186D-02	0.33642794D-02	-0.48784714D-03	-0.24861029D-02
	-0.11178805D-02	0.0	-0.87946964D-03	0.0	-0.14869750D-02	0.0
11	0.13643457D-02	-0.47552971D-02	0.35227617D-02	-0.69054735D-02	0.60216021D-02	-0.87224664D-02
	-0.16954757D-02	0.0	-0.16913559D-02	0.0	-0.13504322D-02	0.0
12	0.63734217D-02	-0.80172335D-02	0.56267948D-02	-0.72474432D-02	0.47753567D-02	-0.66521619D-02
	-0.82190588D-03	0.0	-0.81032422D-03	0.0	-0.93840260D-03	0.0
13	0.40061670D-02	-0.59798426D-02	0.27347561D-02	-0.43588703D-02	0.13786534D-02	-0.29590992D-02
	-0.93683779D-03	0.0	-0.81205709D-03	0.0	-0.79022287D-03	0.0
14	0.33180559D-03	-0.16943486D-02	-0.10173652D-02	-0.26854917D-03	-0.23762029D-02	0.11498801D-02
	-0.68127149D-03	0.0	-0.64295718D-03	0.0	-0.61316138D-03	0.0
15	-0.27674019D-02	0.18651042D-02	-0.21326815D-02	0.15023690D-02	-0.14284045D-02	0.12263039D-02
	-0.45114885D-03	0.0	-0.31515626D-03	0.0	-0.10105029D-03	0.0
16	-0.69397473D-03	0.59161510D-03	0.57855443D-03	-0.26234930D-03	0.18614999D-02	-0.11066741D-02
	-0.51179818D-04	0.0	0.15810257D-03	0.0	0.37741206D-03	0.0
17	0.24906635D-02	-0.17292289D-02	0.24741447D-02	-0.12625100D-02	0.22122861D-02	-0.10694722D-02
	0.38071731D-03	0.0	0.60581735D-03	0.0	0.57140695D-03	0.0
18	0.12911447D-02	0.33887113D-03	0.19000184D-03	0.12543619D-02	-0.65976675D-03	0.24381238D-02
	0.81500793D-03	0.0	0.72218188D-03	0.0	0.88917854D-03	0.0
19	-0.26276981D-03	0.16299250D-02	0.85029702D-03	0.46869126D-03	0.20456646D-02	-0.60683385D-03
	0.68357759D-03	0.0	0.65949414D-03	0.0	0.71941536D-03	0.0
20	0.19969076D-02	-0.11111368D-04	0.12982187D-02	0.32568862D-03	0.45014311D-03	0.50128701D-03
	0.99289811D-03	0.0	0.81195363D-03	0.0	0.47571506D-03	0.0

CYCLE= 40

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	0.11583164D-02	0.37167917D-03	0.11576464D-02	0.37161013D-03
	0.76499781D-03	0.0		

J= 40 TIME (SEC.) = 0.160000D-03
WORK INPUT INTO RING (IN.-LB.) = 0.306676D+06
RING KINETIC ENERGY (IN.-LB.) = 0.145875D+06
RING ELASTIC ENERGY (IN.-LB.) = 0.205421D+04
RING PLASTIC WORK (IN.-LB.) = 0.158747D+06

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	-0.1053D+01	0.0	-0.9475D-01	0.0	0.6647D+01	0.5386D+05	0.8853D+04	-0.9111D-01	-0.8772D-01
2	0.5292D-01	-0.1058D+01	-0.1250D-01	-0.8767D-01	0.1091D+01	0.6552D+01	0.3816D+05	0.4496D+04	-0.8372D-01	-0.8384D-01
3	0.1174D+00	-0.1060D+01	-0.1777D-01	-0.7949D-01	0.2163D+01	0.6279D+01	0.1084D+05	0.1290D+05	-0.7570D-01	-0.7461D-01
4	0.1934D+00	-0.1071D+01	-0.4693D-01	-0.6906D-01	0.3182D+01	0.5819D+01	-0.7622D+04	0.1454D+05	-0.6760D-01	-0.5951D-01
5	0.2795D+00	-0.1143D+01	-0.1529D+00	-0.7870D-01	0.4081D+01	0.5141D+01	-0.6752D+04	0.7745D+03	-0.7018D-01	-0.4511D-01
6	0.3852D+00	-0.1340D+01	-0.2439D+00	-0.7008D-01	0.4769D+01	0.4225D+01	-0.1267D+05	-0.2491D+05	-0.3895D-01	-0.3467D-01
7	0.5902D+00	-0.1342D+01	0.3021D+00	-0.8433D-02	0.5490D+01	0.3259D+01	-0.6211D+05	-0.2595D+05	0.7668D-01	-0.8107D-01
8	0.5178D+00	-0.5519D+00	0.7239D+00	-0.3365D+00	0.6604D+01	0.2784D+01	-0.1368D+05	0.2053D+05	-0.2116D-01	-0.8100D-02
9	0.2542D+00	0.1698D+00	0.2960D+00	-0.1219D+00	0.7563D+01	0.2190D+01	-0.2641D+05	0.2049D+05	-0.9833D-01	0.1233D-01
10	0.1533D+00	0.2743D+00	-0.6777D-01	-0.9241D-02	0.7900D+01	0.1096D+01	-0.1708D+05	0.7755D+04	-0.9206D-02	0.1213D-04
11	0.1078D+00	0.1888D+00	-0.9347D-01	-0.4865D-02	0.7889D+01	-0.1078D+00	-0.1956D+05	-0.7999D+04	0.1347D-03	-0.2343D-02
12	0.8231D-01	0.1061D+00	-0.6193D-01	0.9697D-03	0.7697D+01	-0.1302D+01	-0.2166D+05	-0.1391D+05	0.4816D-02	-0.2896D-02
13	0.7100D-01	0.6786D-01	-0.2294D-01	0.1462D-02	0.7366D+01	-0.2468D+01	-0.2146D+05	-0.9398D+04	0.3084D-02	-0.2347D-02
14	0.6197D-01	0.6574D-01	-0.1463D-02	0.4221D-04	0.6891D+01	-0.3581D+01	-0.1865D+05	-0.1141D+04	0.4418D-03	-0.1152D-02
15	0.4985D-01	0.7360D-01	-0.3729D-02	-0.1724D-02	0.6260D+01	-0.4610D+01	-0.9144D+04	0.2601D+04	-0.2295D-02	0.2061D-04
16	0.3697D-01	0.6845D-01	-0.1474D-01	-0.7174D-03	0.5467D+01	-0.5519D+01	0.4587D+04	-0.3546D+03	-0.8759D-03	0.1933D-03
17	0.2757D-01	0.5550D-01	-0.1219D-01	0.1289D-02	0.4536D+01	-0.6291D+01	0.1758D+05	-0.1856D+04	0.1861D-02	-0.1272D-03
18	0.2106D-01	0.5179D-01	-0.8691D-03	0.1294D-02	0.3500D+01	-0.6916D+01	0.2095D+05	0.3125D+04	0.1589D-02	0.4158D-03
19	0.1339D-01	0.5310D-01	-0.4102D-02	0.3604D-04	0.2383D+01	-0.7378D+01	0.2784D+05	0.2934D+04	-0.3460D-03	0.1216D-02
20	0.6336D-02	0.4856D-01	-0.2951D-02	0.1600D-02	0.1206D+01	-0.7654D+01	0.2731D+05	0.2222D+04	0.1957D-02	0.5514D-03
21	0.0	0.4811D-01	0.0	0.2507D-03	-0.3356D-16	-0.7748D+01			0.2074D-03	0.3808D-03

REACTIONS AT NODE	RV(LBS)	RW(LBS)	RM(IN-LBS)
1	-0.518800D+05	0.0	0.110862D+05
21	0.278118D+05	0.0	-0.422072D+04

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.978209D-01	6	1	3	0.160000D-03
INTERFACE	0.981461D-02	8	1	1	0.800000D-05

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.115832D-02	20	1	0.160000D-03	1
INTERFACE	0.764998D-03	20	1	0.160000D-03	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.766836D-01	7	1	0.160000D-03

CYCLE= 50

ELEMENT	SI STA 1	SO	SI STA 2	SO	SI STA 3	SO
1	-0.83291991D-01	-0.87970637D-01	-0.85830577D-01	-0.85734344D-01	-0.84590237D-01	-0.79481692D-01
	-0.85631314D-01	0.0	-0.85782461D-01	0.0	-0.82035965D-01	0.0
2	-0.93041785D-01	-0.77435964D-01	-0.82810621D-01	-0.70550330D-01	-0.81179949D-01	-0.62141374D-01
	-0.80238875D-01	0.0	-0.76680475D-01	0.0	-0.71660661D-01	0.0
3	-0.78506223D-01	-0.60196326D-01	-0.74335340D-01	-0.51566032D-01	-0.68595544D-01	-0.41240623D-01
	-0.69351275D-01	0.0	-0.62950686D-01	0.0	-0.54918083D-01	0.0
4	-0.66490656D-01	-0.35517774D-01	-0.66169285D-01	-0.31487768D-01	-0.67264975D-01	-0.28945797D-01
	-0.51004215D-01	0.0	-0.48828527D-01	0.0	-0.48105386D-01	0.0
5	-0.61576713D-01	-0.30904427D-01	-0.44924192D-01	-0.28737530D-01	-0.29799028D-01	-0.27898915D-01
	-0.46240570D-01	0.0	-0.36830861D-01	0.0	-0.28848971D-01	0.0
6	0.13157225D-01	-0.50799825D-01	0.71670883D-01	-0.13198430D+00	0.11460213D+00	-0.23294953D+00
	-0.14821300D-01	0.0	-0.30156707D-01	0.0	-0.59173699D-01	0.0
7	0.91399411D-01	-0.15532835D+00	0.49453791D-01	-0.10169252D+00	0.12489607D-01	-0.42208741D-01
	-0.31964470D-01	0.0	-0.26119412D-01	0.0	-0.14859567D-01	0.0
8	-0.34268034D-01	0.38452217D-01	-0.84709582D-01	0.53078028D-01	-0.12293320D+00	0.77845219D-01
	0.92091459D-04	0.0	-0.15815777D-01	0.0	-0.22543993D-01	0.0
9	-0.13512464D+00	0.10689984D+00	-0.85014653D-01	0.65636741D-01	-0.27903432D-01	0.29758178D-01
	-0.14112400D-01	0.0	-0.96889563D-02	0.0	0.92737285D-03	0.0
10	-0.15066162D-01	0.15897973D-01	-0.72195090D-02	0.95255401D-02	-0.81787331D-03	0.17562495D-02
	0.41590572D-03	0.0	0.11530155D-02	0.0	0.46918807D-03	0.0
11	0.10866425D-02	0.31841272D-04	0.36149878D-02	-0.20972504D-02	0.65016874D-02	-0.38430183D-02
	0.55924188D-03	0.0	0.75886868D-03	0.0	0.13293366D-02	0.0
12	0.76610386D-02	-0.36791994D-02	0.91580847D-02	-0.46807603D-02	0.10824265D-01	-0.55596067D-02
	0.19909196D-02	0.0	0.22386622D-02	0.0	0.26323290D-02	0.0
13	0.10440051D-01	-0.46116666D-02	0.85924139D-02	-0.35117802D-02	0.70293909D-02	-0.21742353D-02
	0.29141924D-02	0.0	0.25403169D-02	0.0	0.24275778D-02	0.0
14	0.69723653D-02	-0.12587251D-02	0.45800285D-02	0.21317010D-03	0.30241787D-02	0.15991953D-02
	0.24068201D-02	0.0	0.23965993D-02	0.0	0.23116870D-02	0.0
15	0.20911798D-02	0.26879195D-02	0.11924132D-02	0.36488676D-02	0.26817962D-03	0.45912532D-02
	0.23895497D-02	0.0	0.24206404D-02	0.0	0.24297164D-02	0.0
16	0.17407338D-04	0.49917262D-02	0.62129765D-03	0.43900728D-02	0.13911927D-02	0.39768760D-02
	0.25045666D-02	0.0	0.25056852D-02	0.0	0.26840354D-02	0.0
17	0.23380177D-02	0.28341187D-02	0.37790999D-02	0.16358643D-02	0.52896639D-02	0.50439560D-03
	0.25860682D-02	0.0	0.27074821D-02	0.0	0.28970298D-02	0.0
18	0.54547409D-02	0.45920320D-03	0.44939716D-02	0.13306900D-02	0.35915129D-02	0.22496791D-02
	0.29569720D-02	0.0	0.29123308D-02	0.0	0.29205960D-02	0.0
19	0.30552990D-02	0.27087131D-02	0.26440216D-02	0.28442711D-02	0.25485475D-02	0.33123785D-02
	0.28820060D-02	0.0	0.27441463D-02	0.0	0.29304630D-02	0.0
20	0.27838262D-02	0.33719203D-02	0.33991082D-02	0.26007021D-02	0.38531400D-02	0.16562929D-02
	0.30778733D-02	0.0	0.29999051D-02	0.0	0.27547164D-02	0.0

CYCLE= 50

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	0.34900492D-02	0.24397740D-02	0.34839801D-02	0.24368050D-02
	0.29649116D-02	0.0		

J= 50 TIME (SEC.) = 0.200000D-03

WORK INPUT INTO RING (IN.-LB.)	=	0.306676D+06
RING KINETIC ENERGY (IN.-LB.)	=	0.138058D+06
RING ELASTIC ENERGY (IN.-LB.)	=	0.306025D+04
RING PLASTIC WORK (IN.-LB.)	=	0.165558D+06

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	-0.1234D+01	0.0	-0.8709D-01	0.0	0.6466D+01	0.9157D+05	0.9461D+04	-0.8255D-01	-0.8556D-01
2	0.8586D-01	-0.1223D+01	-0.4904D-03	-0.8556D-01	0.1098D+01	0.6384D+01	0.8969D+05	0.1384D+05	-0.8255D-01	-0.7997D-01
3	0.1770D+00	-0.1220D+01	-0.3767D-02	-0.7902D-01	0.2171D+01	0.6108D+01	0.8549D+05	0.1766D+05	-0.7757D-01	-0.6805D-01
4	0.2827D+00	-0.1268D+01	-0.1066D+00	-0.6738D-01	0.3172D+01	0.5602D+01	0.7951D+05	0.1237D+05	-0.6309D-01	-0.4844D-01
5	0.4025D+00	-0.1404D+01	-0.2114D+00	-0.8382D-01	0.4026D+01	0.4857D+01	0.5847D+05	-0.2744D+04	-0.6260D-01	-0.4403D-01
6	0.5502D+00	-0.1627D+01	-0.2605D+00	-0.6204D-01	0.4684D+01	0.3905D+01	0.5863D+05	-0.1356D+05	-0.2453D-01	-0.3111D-01
7	0.8097D+00	-0.1573D+01	0.3588D+00	-0.1513D-01	0.5433D+01	0.2946D+01	-0.3939D+05	-0.2757D+05	0.9089D-01	-0.7526D-01
8	0.6966D+00	-0.6602D+00	0.8151D+00	-0.4440D+00	0.6585D+01	0.2575D+01	-0.2592D+05	0.1461D+05	-0.1531D-01	-0.7096D-02
9	0.3407D+00	0.2003D+00	0.3968D+00	-0.1632D+00	0.7619D+01	0.2117D+01	-0.8935D+04	0.2298D+05	-0.1016D+00	0.2031D-01
10	0.2113D+00	0.3744D+00	-0.5734D-01	-0.1051D-01	0.8008D+01	0.1054D+01	0.2868D+05	0.1705D+05	-0.1290D-01	0.3454D-02
11	0.1486D+00	0.2912D+00	-0.1080D+00	-0.5414D-02	0.7991D+01	-0.1486D+00	0.5153D+05	0.3671D+04	0.5108D-03	0.2019D-03
12	0.1076D+00	0.1872D+00	-0.9076D-01	0.4377D-03	0.7773D+01	-0.1340D+01	0.6448D+05	-0.3588D+04	0.5951D-02	0.3735D-03
13	0.8823D-01	0.1159D+00	-0.4888D-01	0.5894D-02	0.7406D+01	-0.2499D+01	0.6775D+05	-0.3904D+04	0.9171D-02	0.9084D-03
14	0.7852D-01	0.9430D-01	-0.1224D-01	0.4401D-02	0.6909D+01	-0.3609D+01	0.6954D+05	0.2730D+04	0.5521D-02	0.1379D-02
15	0.6752D-01	0.1013D+00	0.9865D-03	0.2376D-02	0.6272D+01	-0.4640D+01	0.7023D+05	0.9399D+04	0.2412D-02	0.2283D-02
16	0.5302D-01	0.1090D+00	-0.6447D-02	0.1174D-02	0.5484D+01	-0.5559D+01	0.7270D+05	0.1092D+05	0.5582D-03	0.3107D-02
17	0.3820D-01	0.1005D+00	-0.1786D-01	0.2056D-02	0.4554D+01	-0.6333D+01	0.7856D+05	0.5783D+04	0.1999D-02	0.2876D-02
18	0.2742D-01	0.8582D-01	-0.1138D-01	0.4312D-02	0.3510D+01	-0.6950D+01	0.8450D+05	0.5391D+04	0.5079D-02	0.2307D-02
19	0.1877D-01	0.8292D-01	-0.1805D-02	0.3108D-02	0.2387D+01	-0.7408D+01	0.8833D+05	0.9545D+04	0.3197D-02	0.2868D-02
20	0.9065D-02	0.8299D-01	-0.2424D-02	0.2800D-02	0.1209D+01	-0.7689D+01	0.9079D+05	0.8739D+04	0.2687D-02	0.3167D-02
21	0.0	0.8113D-01	0.0	0.3313D-02	-0.5660D-16	-0.7781D+01			0.3645D-02	0.2342D-02

REACTIONS AT NODE	RV(LBS)	RW(LBS)	RM(IN-LBS)
1	-0.797149D+05	0.0	0.587083D+04
21	0.916714D+05	0.0	-0.870350D+04

SUBSTRUCTURE	RSTR	ELE	SURF	STA	TIME
1	0.114602D+00	6	1	3	0.200000D-03
INTERFACE	0.981461D-02	8	1	1	0.800000D-05

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.417591D-02	20	1	0.188000D-03	1
INTERFACE	0.296491D-02	20	1	0.200000D-03	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.908899D-01	7	1	0.200000D-03

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CYCLE= 140

ELEMENT	SI STA 1	SO STA 1	SI STA 2	SO STA 2	SI STA 3	SO STA 3
1	-0.12810922D+00	-0.40886195D-01	-0.11921994D+00	-0.50313177D-01	-0.10548300D+00	-0.54564315D-01
	-0.84497705D-01	0.0	-0.84766559D-01	0.0	-0.80023657D-01	0.0
2	-0.95530795D-01	-0.69543325D-01	-0.92407727D-01	-0.66199999D-01	-0.87588612D-01	-0.60999248D-01
	-0.92537060D-01	0.0	-0.79303863D-01	0.0	-0.74293930D-01	0.0
3	-0.83327493D-01	-0.60415455D-01	-0.73549910D-01	-0.58993405D-01	-0.60254610D-01	-0.53599282D-01
	-0.71871474D-01	0.0	-0.66271658D-01	0.0	-0.56926946D-01	0.0
4	-0.43418638D-01	-0.56927603D-01	-0.34334784D-01	-0.62789168D-01	-0.18494304D-01	-0.67602022D-01
	-0.53173121D-01	0.0	-0.48561976D-01	0.0	-0.43048163D-01	0.0
5	-0.10707260D-01	-0.68535550D-01	-0.47198656D-02	-0.62951683D-01	0.17895469D-02	-0.57293454D-01
	-0.39621405D-01	0.0	-0.33835774D-01	0.0	-0.27751953D-01	0.0
6	0.34511952D-01	-0.69502215D-01	0.73218961D-01	-0.13526797D+00	0.96537485D-01	-0.22254188D+00
	-0.17495131D-01	0.0	-0.31024506D-01	0.0	-0.63002195D-01	0.0
7	0.10002762D+00	-0.18912806D+00	0.45770085D-01	-0.89859198D-01	-0.10837998D-01	0.14466533D-02
	-0.44550219D-01	0.0	-0.22044557D-01	0.0	-0.46956726D-02	0.0
8	-0.45396489D-03	-0.92184587D-02	-0.60304522D-01	0.93965761D-02	-0.10222075D+00	0.52675970D-01
	-0.48362118D-02	0.0	-0.25453973D-01	0.0	-0.24772388D-01	0.0
9	-0.12140667D+00	0.12058654D+00	-0.92534251D-01	0.73840707D-01	-0.42740408D-01	0.43529141D-01
	-0.41006134D-03	0.0	-0.93467721D-02	0.0	0.39436676D-03	0.0
10	-0.39117256D-01	0.40143279D-01	-0.38098152D-01	0.36072446D-01	-0.36846733D-01	0.32060454D-01
	0.51301153D-03	0.0	-0.10128531D-02	0.0	-0.23931399D-02	0.0
11	-0.41347296D-01	0.43614099D-01	-0.31804880D-01	0.28617404D-01	-0.19339262D-01	0.16765285D-01
	0.11334018D-02	0.0	-0.15937379D-02	0.0	-0.12869883D-02	0.0
12	-0.14950309D-01	0.13780718D-01	-0.96915753D-02	0.89298830D-02	-0.37466583D-02	0.49621693D-02
	-0.58479572D-03	0.0	-0.38084615D-03	0.0	0.60775553D-03	0.0
13	-0.11085383D-02	0.30501530D-02	0.46724469D-03	0.41068368D-03	0.12639242D-02	-0.29926296D-02
	0.97080736D-03	0.0	0.43896418D-03	0.0	-0.86435274D-03	0.0
14	0.20658992D-02	-0.37086407D-02	0.51868641D-02	-0.48292825D-02	0.86903433D-02	-0.55405985D-02
	-0.82137072D-03	0.0	0.17879080D-03	0.0	0.15748724D-02	0.0
15	0.10161123D-01	-0.68550918D-02	0.10042931D-01	-0.77766497D-02	0.99999110D-02	-0.87008306D-02
	0.16530156D-02	0.0	0.11331406D-02	0.0	0.64954021D-03	0.0
16	0.97354994D-02	-0.94250429D-02	0.96584395D-02	-0.11276920D-01	0.10751532D-01	-0.11998136D-01
	0.15522828D-03	0.0	-0.80924027D-03	0.0	-0.62330159D-03	0.0
17	0.11177458D-01	-0.12999888D-01	0.92785103D-02	-0.10803034D-01	0.75511482D-02	-0.85349755D-02
	-0.91121476D-03	0.0	-0.76226197D-03	0.0	-0.49191364D-03	0.0
18	0.58787691D-02	-0.64332090D-02	0.35592468D-02	-0.41599223D-02	0.14720277D-02	-0.16687344D-02
	-0.27721997D-03	0.0	-0.30033775D-03	0.0	-0.98353319D-04	0.0
19	0.39496624D-03	-0.98115850D-03	-0.16598408D-02	0.99790258D-03	-0.37377322D-02	0.29702744D-02
	-0.29309613D-03	0.0	-0.33096911D-03	0.0	-0.38372890D-03	0.0
20	-0.45844876D-02	0.36372301D-02	-0.50300274D-02	0.31713611D-02	-0.55267752D-02	0.26779461D-02
	-0.47362874D-03	0.0	-0.92933313D-03	0.0	-0.14244146D-02	0.0

CYCLE= 140
STRAIN AT ADDITIONAL POINTS

	SI	SO	EI	EO
1	-0.51160675D-02	0.30841715D-02	-0.51292220D-02	0.30794301D-02
	-0.10159480D-02	0.0		

J= 140 TIME (SEC.) = 0.560000D-03
WORK INPUT INTO RING (IN.-LB.) = 0.306676D+06
RING KINETIC ENERGY (IN.-LB.) = 0.119210D+06
RING ELASTIC ENERGY (IN.-LB.) = 0.390173D+04
RING PLASTIC WORK (IN.-LB.) = 0.183565D+06

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN (IN)	STRAIN (OUT)
1	0.0	-0.2848D+01	0.0	-0.1123D+00	0.0	0.4852D+01	-0.1780D+05	0.1262D+05	-0.1176D+00	-0.7127D-01
2	0.3136D+00	-0.2964D+01	-0.2086D+00	-0.1184D+00	0.1051D+01	0.4629D+01	-0.9509D+04	0.8504D+04	-0.9412D-01	-0.7619D-01
3	0.6461D+00	-0.3189D+01	-0.2880D+00	-0.1290D+00	0.2009D+01	0.4091D+01	-0.1364D+05	-0.6997D+04	-0.8244D-01	-0.6940D-01
4	0.1013D+01	-0.3441D+01	-0.3324D+00	-0.1166D+00	0.2837D+01	0.3335D+01	-0.5376D+04	-0.1609D+05	-0.5474D-01	-0.5397D-01
5	0.1459D+01	-0.3614D+01	-0.2466D+00	-0.5892D-01	0.3582D+01	0.2448D+01	-0.5336D+04	-0.1802D+05	-0.1972D-01	-0.4794D-01
6	0.1984D+01	-0.3537D+01	-0.7016D-01	-0.1363D-01	0.4346D+01	0.1541D+01	0.5954D+05	-0.4990D+04	-0.2689D-02	-0.3623D-01
7	0.2484D+01	-0.2968D+01	0.5654D+00	-0.1362D+00	0.5288D+01	0.7719D+00	0.7480D+05	0.6308D+04	0.7590D-01	-0.9593D-01
8	0.2110D+01	-0.1534D+01	0.9802D+00	-0.1189D+01	0.6452D+01	0.9195D+00	-0.3158D+06	-0.3014D+05	-0.3257D-02	0.2727D-02
9	0.1178D+01	-0.1659D+00	0.7638D+00	-0.4284D+00	0.7529D+01	0.1207D+01	-0.7785D+05	0.1309D+05	-0.7270D-01	0.3833D-01
10	0.9131D+00	0.5545D+00	0.2645D+00	-0.5549D-01	0.8296D+01	0.3894D+00	-0.1264D+05	0.1869D+05	-0.2790D-01	0.7811D-02
11	0.7574D+00	0.8661D+00	0.4037D-01	-0.2083D-01	0.8566D+01	-0.7574D+00	-0.8017D+04	0.1658D+05	-0.2977D-01	0.1010D-01
12	0.5923D+00	0.8911D+00	-0.1425D+00	-0.1873D-01	0.8393D+01	-0.1929D+01	-0.1430D+04	0.1323D+05	-0.1220D-01	0.2997D-02
13	0.4363D+00	0.7572D+00	-0.1990D+00	-0.2041D-01	0.7908D+01	-0.3028D+01	0.4979D+03	0.8959D+04	-0.1109D-02	0.1703D-02
14	0.3072D+00	0.5713D+00	-0.1988D+00	-0.1994D-01	0.7230D+01	-0.4029D+01	0.1312D+04	0.2232D+04	0.6525D-03	-0.1850D-02
15	0.2144D+00	0.3862D+00	-0.1686D+00	-0.8248D-02	0.6416D+01	-0.4926D+01	0.1342D+04	-0.6890D+04	0.8011D-02	-0.5169D-04
16	0.1601D+00	0.2433D+00	-0.1146D+00	-0.1296D-02	0.5504D+01	-0.5730D+01	-0.4708D+03	-0.1382D+05	0.7626D-02	-0.1779D-02
17	0.1303D+00	0.1641D+00	-0.5129D-01	0.4186D-02	0.4517D+01	-0.6439D+01	0.1342D+04	-0.1352D+05	0.8552D-02	-0.3616D-02
18	0.1105D+00	0.1610D+00	0.9516D-02	0.3207D-02	0.3470D+01	-0.7054D+01	-0.7761D+03	-0.8170D+04	0.5045D-02	-0.2103D-02
19	0.8371D-01	0.2056D+00	0.3287D-01	-0.1497D-03	0.2363D+01	-0.7545D+01	-0.8954D+03	0.2999D+04	0.6629D-03	-0.4266D-03
20	0.4559D-03	0.2540D+00	0.2482D-01	-0.2718D-02	0.1199D+01	-0.7863D+01	-0.4075D+04	0.9026D+04	-0.3414D-02	0.6162D-03
21	0.0	0.2726D+00	0.0	-0.3635D-02	-0.1902D-15	-0.7973D+01			-0.4654D-02	-0.5493D-03

REACTIONS AT NODE	RV (LBS)	RW (LBS)	RM (IN-LBS)
1	0.166531D+05	0.0	0.141255D+05
21	-0.389145D+04	0.0	-0.101930D+05

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.120587D+00	9	2	1	0.560000D-03
INTERFACE	0.981461D-02	8	1	1	0.800000D-05

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.483302D-02	20	1	0.384000D-03	1
INTERFACE	0.296491D-02	20	1	0.200000D-03	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.985056D-01	7	1	0.556000D-03

CYCLE= 150

ELEMENT	SI (STA 1)	SO (STA 1)	SI (STA 2)	SO (STA 2)	SI (STA 3)	SO (STA 3)
1	-0.13102706D+00	-0.38707042D-01	-0.12075693D+00	-0.48598696D-01	-0.10610727D+00	-0.53811807D-01
	-0.84867054D-01	0.0	-0.84677815D-01	0.0	-0.79959540D-01	0.0
2	-0.95489879D-01	-0.70091898D-01	-0.91602721D-01	-0.66943883D-01	-0.86393428D-01	-0.62316200D-01
	-0.82790889D-01	0.0	-0.79273302D-01	0.0	-0.74354814D-01	0.0
3	-0.82361202D-01	-0.61254137D-01	-0.72444246D-01	-0.59993480D-01	-0.58730005D-01	-0.54460354D-01
	-0.71807670D-01	0.0	-0.66218863D-01	0.0	-0.56595180D-01	0.0
4	-0.48473417D-01	-0.56825030D-01	-0.34264972D-01	-0.63075427D-01	-0.18516572D-01	-0.67464132D-01
	-0.52649224D-01	0.0	-0.48670199D-01	0.0	-0.42990352D-01	0.0
5	-0.10394109D-01	-0.69563802D-01	-0.46836786D-02	-0.64196775D-01	0.21775549D-02	-0.58109173D-01
	-0.39978956D-01	0.0	-0.34440227D-01	0.0	-0.27965809D-01	0.0
6	0.34911294D-01	-0.69841287D-01	0.73277954D-01	-0.13589424D+00	0.56996954D-01	-0.22276553D+00
	-0.17464996D-01	0.0	-0.31308144D-01	0.0	-0.62884288D-01	0.0
7	0.10184356D+00	-0.19716494D+00	0.42015706D-01	-0.86095048D-01	-0.18009495D-01	0.19149860D-01
	-0.47660693D-01	0.0	-0.22039671D-01	0.0	0.57018264D-03	0.0
8	0.10126008D-01	-0.17403924D-01	-0.49084704D-01	0.56453848D-02	-0.98389528D-01	0.46704163D-01
	-0.36389580D-02	0.0	-0.21719660D-01	0.0	-0.25842682D-01	0.0
9	-0.12191013D+00	0.12390818D+00	-0.93376377D-01	0.74271867D-01	-0.41768435D-01	0.42743934D-01
	0.97902672D-03	0.0	-0.95522550D-02	0.0	0.48774964D-03	0.0
10	-0.39722799D-01	0.39898308D-01	-0.37606678D-01	0.35852999D-01	-0.36300274D-01	0.31812443D-01
	0.58775494D-03	0.0	-0.87663958D-03	0.0	-0.22439154D-02	0.0
11	-0.41216966D-01	0.44537314D-01	-0.32818617D-01	0.30810298D-01	-0.22039434D-01	0.19594035D-01
	0.16602238D-02	0.0	-0.10041594D-02	0.0	-0.12226995D-02	0.0
12	-0.18559027D-01	0.18500237D-01	-0.12787947D-01	0.13490163D-01	-0.66541102D-02	0.89243258D-02
	-0.79395024D-04	0.0	0.35110805D-03	0.0	0.11351078D-02	0.0
13	-0.34936686D-02	0.57170727D-02	-0.88667622D-03	0.26416110D-02	0.90870833D-03	-0.11965625D-02
	0.11117021D-02	0.0	0.87746740D-03	0.0	-0.14392707D-03	0.0
14	0.21954404D-02	-0.24932665D-02	0.55898889D-02	-0.38733925D-02	0.94582236D-02	-0.47334575D-02
	-0.14891301D-03	0.0	0.85824821D-03	0.0	0.23623830D-02	0.0
15	0.11068924D-01	-0.60246852D-02	0.10897531D-01	-0.66839348D-02	0.10734334D-01	-0.74177704D-02
	0.25216692D-02	0.0	0.21067981D-02	0.0	0.16582818D-02	0.0
16	0.11184040D-01	-0.83589869D-02	0.13120137D-01	-0.10738437D-01	0.15965772D-01	-0.12265604D-01
	0.14125263D-02	0.0	0.11908496D-02	0.0	0.18500841D-02	0.0
17	0.16546849D-01	-0.13398063D-01	0.13134676D-01	-0.10103874D-01	0.95497951D-02	-0.71267550D-02
	0.15743927D-02	0.0	0.15154012D-02	0.0	0.12115201D-02	0.0
18	0.69029728D-02	-0.43851167D-02	0.42684777D-02	-0.20560788D-02	0.19635659D-02	0.59986537D-03
	0.12589280D-02	0.0	0.11061995D-02	0.0	0.12817156D-02	0.0
19	0.11600419D-02	0.90306516D-03	-0.20405386D-03	0.23054187D-02	-0.16182621D-02	0.36686571D-02
	0.10315535D-02	0.0	0.10506824D-02	0.0	0.10251975D-02	0.0
20	-0.23721132D-02	0.43577624D-02	-0.29383928D-02	0.42673224D-02	-0.34126239D-02	0.42975344D-02
	0.99282462D-03	0.0	0.66446480D-03	0.0	0.44245526D-03	0.0

CYCLE= 150

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.30303549D-02	0.42644153D-02	-0.30349604D-02	0.42553613D-02
	0.61703023D-03	0.0		

J= 150 TIME (SEC.) = 0.600000D-03

WORK INPUT INTO RING (IN.-LB.) = 0.306676D+06
RING KINETIC ENERGY (IN.-LB.) = 0.117574D+06
RING ELASTIC ENERGY (IN.-LB.) = 0.407289D+04
RING PLASTIC WORK (IN.-LB.) = 0.185030D+06

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	-0.3064D+01	0.0	-0.1144D+00	0.0	0.4636D+01	-0.1285D+05	0.1406D+05	-0.1202D+00	-0.7105D-01
2	0.3454D+00	-0.3185D+01	-0.2184D+00	-0.1212D+00	0.1047D+01	0.4405D+01	-0.8125D+04	0.7112D+04	-0.9448D-01	-0.7642D-01
3	0.7107D+00	-0.3412D+01	-0.2931D+00	-0.1301D+00	0.2001D+01	0.3858D+01	-0.1211D+05	-0.8880D+04	-0.8162D-01	-0.6971D-01
4	0.1113D+01	-0.3654D+01	-0.3312D+00	-0.1149D+00	0.2828D+01	0.3100D+01	-0.6428D+04	-0.1587D+05	-0.5342D-01	-0.5351D-01
5	0.1591D+01	-0.3807D+01	-0.2443D+00	-0.5815D-01	0.3575D+01	0.2214D+01	-0.7967D+04	-0.1749D+05	-0.1949D-01	-0.4796D-01
6	0.2144D+01	-0.3701D+01	-0.6402D-01	-0.1289D-01	0.4344D+01	0.1311D+01	0.5131D+05	-0.6476D+04	-0.2253D-02	-0.3628D-01
7	0.2666D+01	-0.3096D+0	0.5736D+00	-0.1408D+00	0.5292D+01	0.5490D+00	0.9168D+05	0.9169D+04	0.7760D-01	-0.9813D-01
8	0.2264D+01	-0.1625D+01	0.9658D+00	-0.1259D+01	0.6441D+01	0.7405D+00	-0.3132D+06	-0.3054D+05	-0.2326D-02	0.6236D-02
9	0.1263D+01	-0.2259D+00	0.7935D+00	-0.4650D+00	0.7498D+01	0.1109D+01	-0.8049D+05	0.1358D+05	-0.6965D-01	0.4049D-01
10	0.9830D+00	0.5379D+00	0.2907D+00	-0.6299D-01	0.8290D+01	0.3178D+00	-0.8690D+04	0.1839D+05	-0.2747D-01	0.7396D-02
11	0.8213D+00	0.8929D+00	0.6873D-01	-0.2206D-01	0.8593D+01	-0.8213D+00	-0.1605D+04	0.1608D+05	-0.2938D-01	0.1030D-01
12	0.6498D+00	0.9578D+00	-0.1238D+00	-0.1797D-01	0.8450D+01	-0.1996D+01	0.2568D+04	0.1597D+05	-0.1488D-01	0.4029D-02
13	0.4813D+00	0.8401D+00	-0.2034D+00	-0.2267D-01	0.7973D+01	-0.3097D+01	0.5599D+04	0.1013D+05	-0.3188D-02	0.2655D-02
14	0.3362D+00	0.6470D+00	-0.2141D+00	-0.2278D-01	0.7285D+01	-0.4089D+01	0.2103D+05	0.4738D+04	0.8369D-03	-0.9156D-03
15	0.2295D+00	0.4454D+00	-0.1855D+00	-0.1040D-01	0.6455D+01	-0.4973D+01	0.2959D+05	-0.3835D+04	0.8902D-02	0.7707D-03
16	0.1653D+00	0.2833D+00	-0.1323D+00	-0.2641D-02	0.5528D+01	-0.5762D+01	0.3397D+05	-0.9585D+04	0.8404D-02	-0.7542D-03
17	0.1323D+00	0.1866D+00	-0.6011D-01	0.7860D-02	0.4529D+01	-0.6458D+01	0.4090D+05	-0.8542D+04	0.1354D-01	-0.1822D-02
18	0.1127D+00	0.1810D+00	0.1028D-01	0.4561D-02	0.3477D+01	-0.7073D+01	0.3762D+05	-0.2570D+04	0.6344D-02	-0.5375D-03
19	0.8415D-01	0.2245D+00	0.2941D-01	0.8758D-03	0.2369D+01	-0.7563D+01	0.3919D+05	0.6865D+04	0.1370D-02	0.1125D-02
20	0.4531D-01	0.2679D+00	0.2181D-01	-0.7761D-03	0.1202D+01	-0.7877D+01	0.3718D+05	0.1126D+05	-0.1331D-02	0.1842D-02
21	0.0	0.2851D+00	0.0	-0.1572D-02	-0.1989D-15	-0.7985D+01			-0.2553D-02	0.1378D-02

REACTIONS AT NODE	RV(LBS)	RW(LBS)	RM(IN-LBS)
1	0.150261D+05	0.0	0.152230D+05
21	0.369255D+05	0.0	-0.123557D+05

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.123908D+00	9	2	1	0.600000D-03
INTERFACE	0.981461D-02	8	1	1	0.800000D-05

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.488302D-02	20	1	0.384000D-03	1
INTERFACE	0.296491D-02	20	1	0.200000D-03	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.100950D+00	7	1	0.596000D-03

THE LARGEST COMPUTED STRAINS FOR EACH SUBSTRUCTURE-- MAIN AND BRANCHES -- ARE PRINTED BELOW, 1= INNER 2= OUTER SURF

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.123908D+00	9	2	1	0.600000D-03
INTERFACE	0.981461D-02	8	1	1	0.800000D-05

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.488302D-02	20	1	0.384000D-03	1
INTERFACE	0.296491D-02	20	1	0.200000D-03	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.100950D+00	7	1	0.596000D-03

THERE ARE NO CARDS PUNCHED FOR CONTINUATION

7.2 CIVM-JET 5B Example: A Fragment-Impacted, Elastic-Foundation-Supported, Variable-Thickness, Two-Layer, Partial Ring with One Support Branch

7.2.1 Problem Description

The geometry of the main structure, as shown in Fig. 12, is a partial ring composed of an initially-straight portion and a circular portion. The straight section is 10.0-in long, 1.5-in wide, and varies linearly in thickness from 0.3-in at its pinned end to 0.1-in where it joins the circular portion. The circular section has a 5.0-in mean radius, a 1.5-in width, a 0.1-in uniform thickness, and consists of a 60° arc. The partial ring is supported by a pinned joint at its left-hand end, a branch connected at the straight-circular junction, and an elastic foundation located as depicted in Fig. 12. This foundation consists of arbitrarily chosen normal k_N and tangential k_T stiffness equal to 1500 psi and 3000 psi, respectively.

The "main structure" of the partial ring is called substructure one (1) and is assumed to consist of two layers of material firmly attached to each other at the interface. The inner layer and the outer layer of the structure are equal thicknesses of aluminum and steel, respectively.

The main structure has a steel branch attached to its steel outer layer. The branch is 1.0-in wide, 2.23607-in long, and has a constant thickness of 0.4 in. The branch has a slope discontinuity between its two equal-length elements. The branch attaches to the steel outer surface of the main structure at the eleventh node of the ring and is clamped at its other end.

The aluminum material of the main structure's inner layer has a yield stress of 46,000 psi, an elastic modulus of 10^7 psi, and is represented by a two mechanical-sublayer model defined by the following stress-strain (σ, ε) pairs: σ_1, ε_1 = 46,000 psi, .0046 and σ_2, ε_2 = 58,000 psi, 0.18000. The strain-rate constants were chosen to be D = 6500 sec^{-1} and p = 4. The mass density is 0.250×10^{-3} $(lb\text{-}sec^2)/in^4$. The steel material used in the main structure's outer layer and in the branch has an elastic modulus of 29×10^6 psi, a yield stress of 80,950 psi, and is represented by a three-mechanical-sublayer model defined by σ_1, ε_1 = 80,950 psi, .00279; σ_2, ε_2 = 105,300 psi, .02250, and σ_3, ε_3 = 121,000 psi, .20000. The strain rate constants for the steel are assumed to be D = 40.4 sec^{-1} and p = 5, with a mass density of $.733085 \times 10^{-3}$ $(lb\text{-}sec^2)/in^4$.

The variable-thickness straight portion of the structure is modeled by 10 equal-length finite elements; 6 equal-arc finite elements represent the constant thickness curved section; and 2 equal-length elements represent the constant thickness branch. This makes a total of 18 finite elements used for the entire structure.

The elements of the main structure are initially numbered consecutively from 1 to 16, and the branch elements are initially numbered from 1 to 2; this is depicted in Fig. 12b. The program will then renumber the elements from left to right to include the branch elements in the global system; the resulting renumbering is shown in Fig. 12c.

The attacking fragment has the following parameters (see Fig. 12a): radius $r_f = 0.5$ in, mass $m_f = .385610 \times 10^{-3}$ (lb-sec^2/in); mass moment of inertia $I_f = 0.482014 \times 10^{-4}$ (lb-sec^2-in); initial translational velocity components: $\dot{Y}_f = 2607.96$ in/sec, $\dot{Z}_f = 1482.75$ in/sec; initial rotational velocity $\dot{\theta}_f = 0.0$; initial C.G. position $Y_{CG} = 6.0$ in, $Z_{CG} = -2.0$ in. The value of the coefficient of restitution, e, is set at 1.0 to represent a perfectly-elastic impact reaction, and the coefficient of friction is set to 0.0.

The strain is to be calculated at each of the three spanwise Gaussian stations and each node of the main structure and the branch. Also, 3 additional points at which strain predictions are desired are requested. Two of these are on main structural elements 9 and 11; the point on element 9 is located near the point of first impact and the point on element 11 is located near the branch connection ($\bar{s}$ coordinates 0.53 and 0.05, respectively). The additional strain point on the branch is located at $\bar{s} = 0.50$ of the first element; this corresponds to the same location as the second Gaussian station on this element. The strains should be exactly the same at this point since both the Gaussian station and the additional point are at the same physical location.

The CIVM-JET 5B program will be used to calculate the structural response of the ring and the motion of the fragment, using a time step of 2 microseconds. Printout of structural responses and fragment position data are desired at intervals of every 20 time steps (or cycles) until 300 cycles have been completed.

7.2.2 Input Data

The values to be punched on the data cards are as follows:

Card 1 — 10I5

IK = 16

ICP = 0

NLAY = 2

LREF = 1

NOGA = 3

NFL = 4

MM = 790

M1 = 490

M2 = 20

ICON = 0

Card 2 — 2I5

NSFL(1,1) = 2

NSFL(2,1) = 3

Card 3A — 3D15.6

DENS(1,1) = 0.250000D-03

DS(1,1) = 0.650000D+04

P(1,1) = 0.400000D+01

Card 4AA — 4D15.6

EPS(1,1,1) = 0.460000D-02

SIG(1,1,1) = 0.460000D+05

EPS(1,2,1) = 0.180000D+00

SIG(1,2,1) = 0.580000D+05

Card 3B — 3D15.6

DENS(2,1) = 0.733085D-03

DS(2,1) = 0.404000D+02

P(2,1) = 0.500000D+01

Card 4BA — 4D15.6

EPS(2,1,1) = 0.279000D-02

SIG(2,1,1) = 0.809500D+05

EPS(2,2,1) = 0.225000D-01

SIG(2,2,1) = 0.105300D+06

Card 4BB 2D15.6

EPS(2,3,1) = 0.200000D+00

SIG(2,3,1) = 0.121000D+06

Card 5 2D15.6

B(1) = 0.150000D+01

DELTAT = 0.200000D-05

Card 6A 3D15.6

Y(1) = 0.0

Z(1) = 0.0

ANG(1) = 0.0

.
.
.

Additional cards are punched in the same format until all 17 nodes of the main structure are described.

Y(17) = 0.143301D+02

Z(17) = 0.250000D+01

ANG(17) = 0.600000D+02

Card 7A 5D15.6

H(1,1) = 0.150000D+00

H(1,2) = 0.150000D+00

H(2,1) = 0.140000D+00

H(2,2) = 0.140000D+00

H(3,1) = 0.130000D+00

.
.
.

Additional cards are punched until all the nodal thicknesses for each layer are described, with five data entries per card.

.
.
.

H(16,1) = 0.050000D+00

H(16,2) = 0.050000D+00

H(17,1) = 0.050000D+00

H(17,2) = 0.050000D+00

Card 8A — I5

NDIS = 0

Card 9

NBR = 1

Card 9A — I5,4D15.6

NSFL(1,2) = 3

B(2) = 0.100000D+01

DENS(1,2) = 0.733085D-03

DS(1,2) = 0.404000D+02

P(1,2) = 0.500000D+01

Card 9AA — 4D15.6

EPS(1,1,2) = 0.279000D-02

SIG(1,1,2) = 0.809500D+05

EPS(1,2,2) = 0.225000D-01

SIG(1,2,2) = 0.105300D+06

Card 9AB — 2D15.6

EPS(1,3,2) = 0.200000D+00

SIG(1,3,2) = 0.121000D+06

Card 9B — 4I5

NELT(1) = 2

NODP(1) = 11

LHIT(1) = 0

LATT(1) = 0

Card 9BA — 4D15.6

YB(1,1) = 0.105000D+02

ZB(1,1) = 0.100000D+01

ANB(1,1) = 0.634349D+02

HB(1,1) = 0.400000D+00

Card 9BB 4D15.6

YB(1,2) = 0.115000D+02

ZB(1,2) = 0.150000D+01

ANB(1,2) = 0.265651D+02

HB(1,2) = 0.400000D+00

Card 9BC 4D15.6

YB(1,2) = 0.100000D+02

ZB(1,3) = 0.0

ANB(1,3) = 0.634349D+02

HB(1,3) = 0.400000D+00

NOTE: This is the attachment point information.

Card 9C I5

NDISB = 1

Card 9CA 2I5,D15.6

NEDIB = 2

NBDI = 1

ANGB = 0.265651D+02

Card 9D I5

NBCONB = 1

Card 9DA 3I5

NBCB(1) = 2

NODBB(1) = 2

LBR(1) = 1

Card 10 3I5

NOP = 3

NASP = 3

NTERF = 1

Card 10A 2I5,D15.6

NSBS(1) = 1

NSEL(1) = 9

AZET(1) = 0.530000D+00

Card 10B 2I5,D15.6

NSBS(2) = 2

NSEL(2) = 1

AZET(2) = 0.500000D+00

Card 10C 2I5,D15.6

NSBS(3) = 1

NSEL(3) = 1

AZET(3) = 0.500000D-01

Card 11 3D25.16

AXG(1) = 0.1127016653792585D+00

AXG(2) = 0.5000000000000000D+00

AXG(3) = 0.8872983346207415D+00

Card 12 3D25.16

AWG(1) = 0.2777777777777778D+00

AWG(2) = 0.4444444444444444D+00

AWG(3) = 0.2777777777777778D+00

Card 13A 3D25.16

TXG(1) = -0.8611363115940530D+00

TXG(2) = -0.3399810435848560D+00

TXG(3) = 0.3399810435848560D+00

Card 13B D25.16

TXG(4) = 0.8611363115940530D+00

Card 14A 3D25.16

TWG(1) = 0.3478548451374540D+00

TWG(2) = 0.6521451548625460D+00

TWG(3) = 0.6521451548625460D+00

CArd 14B D25.16

TWG(4) = 0.3478548451374540D+00

Card 15 3I5

NBCOND = 1

NBC(1) = 3

NODEB(1) = 1

Card 16 3I5

NQR = 2

NORP = 0

NORU = 2

Card 16B 3D15.6

SCTU = 0.300000D+04

SCTW = 0.0

SCRU = 0.150000D+04

Card 16BB 4I5

NRST(1) = 9

NREU(1) = 2

NRST(2) = 13

NREU(2) = 3

Card 17 I5,D15.6

NF = 1

EFLN(1) = 0.0

Card 18AA 5D15.6

FH(1) = 0.100000D+01

FCG(1) = -0.200000D+01

FCGX(1) = 0.600000D+01

FMASS(1) = 0.385610D-03

FMOI(1) = 0.482014D-04

Card 18AB D15.6

UNK(1) = 0.0

Card 18AC 5D15.6

UDOT(1) = 0.260796D+04

WDOT(1) = 0.148275D+04

ADOT(1) = 0.0

TPRIM(1) = 0.960000D-03

CR(1) = 0.100000D+01

Card 19 I5

ICONT = 0

This is the last data card for this CIVM-JET 5B run.

THIS IS THE INPUT DECK FOR EXAMPLE 7.2

```
  16     0     2     1     3     4   790   490    20     0
   2     3
00.250000D-03  00.650000D+04  00.400000D+01
00.460000D-02  00.460000D+05  00.180000D+00  00.580000D+05
00.733085D-03  00.404000D+02  00.500000D+01
00.279000D-02  00.809500D 05  00.225000D-01  00.105300D 05
00.200000D 00  00.121000D 06
00.150000D+01  00.200000D-05
00.0           00.0           00.0           00.300000D+00
00.100000D+01  00.0           00.0           00.280000D+00
00.200000D+01  00.0           00.0           00.260000D+00
00.300000D+01  00.0           00.0           00.240000D+00
00.400000D+01  00.0           00.0           00.220000D+00
00.500000D+01  00.0           00.0           00.200000D+00
00.600000D+01  00.0           00.0           00.180000D+00
00.700000D+01  00.0           00.0           00.160000D+00
00.800000D+01  00.0           00.0           00.140000D+00
00.900000D+01  00.0           00.0           00.120000D+00
00.100000D+02  00.0           00.0           00.100000D+00
00.108682D+02  -0.759612D-01  -0.100000D+02  00.100000D+00
00.117101D+02  -0.301537D+00  -0.200000D+02  00.100000D+00
00.125000D+02  -0.669873D+00  -0.300000D+02  00.100000D+00
00.132139D+02  -0.116978D+01  -0.400000D+02  00.100000D+00
00.138302D+02  -0.178606D+01  -0.500000D+02  00.100000D+00
00.143301D+02  -0.250000D+01  -0.600000D+02  00.100000D+00
00.150000D+00  00.150000D+00  00.140000D+00  00.140000D+00  00.130000D+00
00.130000D+00  00.120000D+00  00.120000D+00  00.110000D+00  00.110000D+00
00.100000D+00  00.100000D+00  00.090000D+00  00.090000D+00  00.080000D+00
00.080000D+00  00.070000D+00  00.070000D+00  00.060000D+00  00.060000D+00
00.050000D+00  00.050000D+00  00.050000D+00  00.050000D+00  00.050000D+00
00.050000D+00  00.050000D+00  00.050000D+00  00.050000D+00  00.050000D+00
00.050000D+00  00.050000D+00  00.050000D+00  00.050000D+00
   0
   1
   3  00.100000D+01  00.733085D-03  00.404000D+02  00.500000D+01
00.279000D-02  00.809500D 05  00.225000D-01  00.105300D 05
```


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```
00.200000D 03   00.121000D 06
  2   11    0     0
00.105000D+02  00.100000D+01  00.634349D+02  00.400000D+00
00.115000D+02  00.150000D+01  00.265651D+02  00.400000D+00
00.100000D+02  00.0           00.634349D+02  00.400000D+00
  1
  2     1  00.265651D+02
  1
  2     2     1
  3     3     1
  1     9  00.530000D+00
  2     1  00.500000D+00
  1    11  00.500000D-01
00.1127016653792585D+00  00.5000000000000000D+00  00.8872983346207415D+00
00.2777777777777778D+00  00.4444444444444444D+00  00.2777777777777778D+00
-0.8611363115940530D+00  -0.3399810435848560D+00  00.3399810435848560D+00
00.8611363115940530D+00
00.3478548451374540D+00  00.6521451548625460D+00  00.6521451548625460D+00
00.3478548451374540D+00
  1     3     1
  2     0     2
00.300000D+04  00.0           00.150000D+04
  9     2    13     3
  1  00.0
00.100000D+01  -0.200000D+01  00.600000D+01  00.385610D-03  00.482014D-04
00.0
00.260796D+04  00.148275D+04  00.0           00.960000D-03  00.100000D+01
  0
```

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7.2.3 Solution Output Data for Example 2

The following is the output obtained as a result of a 600 microsecond CIVM-JET 5B analysis of this two layer partial ring example.

The numbering system for the nodes and elements is listed as well as an identification of the branch attachment point and the slopes at the branch connection and at the slope discontinuity. The partial ring initial geometry (for both layers), boundary conditions, and elastic foundations are defined as well as all the necessary data pertaining to the impacting fragment. A reference time step is computed and printed for a comparison against the user-designated time step of 2 microseconds in this case.

Each impact is recorded (there are 2 impacts during this run) and the essential data concerning element number, fragment number, time, location and post-impact fragment energies are output. For each printout cycle, an update of each nodal position, the fragment position, the strains at each Gaussian point and each addition strain point (inner and outer surfaces and interface) and at each node, and the reaction forces are given.

Initial impact occurs on element 9 at 967.796 microseconds after fragment release; this is computational time cycle 484. During this computer run the maximum strain reaches 3.36% on the main structure and only 2.73% on the branch.

Note that for conciseness only a portion of the requested output is presented here. Included are: all initial problem data, printout at time cycles 490, 510, 530, 550, 570, 590, ... skip to 770, 790 (last); a record of all impacts occurring up to time cycle 790 is retained.

THIS IS RUN NUMBER 1 FOR THIS CIVM-JET 5B SUBMITTAL

THERE ARE 18 ELEMENTS AND 19 NODES

THERE ARE 1 BRANCHES AND THEY ARE AT NODES 11

THE GLOBAL SLOPE(RAD) AT EACH BRANCH CONNECTION: 0.110715D+01

THE ATTACHMENT POINT CODE FOR THE 1 BRANCHES IS AS FOLLOWS:
0
WHERE -1= INNER AND 0 = OUTER SURFACES. 1,2,3 INDICATE MIDSURFACE OF CORRESPONDING LAYER.

PRESENT ELEM. NO.	NODE1	NODE2	SUBSTRUCTURE	SUBST. ELEM. NO.
1	1	2	1	1
2	2	3	1	2
3	3	4	1	3
4	4	5	1	4
5	5	6	1	5
6	6	7	1	6
7	7	8	1	7
8	8	9	1	8
9	9	10	1	9
10	10	11	1	10
11	11	12	2	1
12	12	13	2	2
13	11	14	1	11
14	14	15	1	12
15	15	16	1	13
16	16	17	1	14
17	17	18	1	15
18	18	19	1	16

THE UPDATED NODE NUMBERS FOR THE MAIN STRUCTURE, GIVEN IN THEIR ORIGINAL NUMBERING ORDER:

1 2 3 4 5 6 7 8 9 10 11 14 15 16 17 18 19

NOTE: THE ELEMENT NUMBERS REFERRED TO BELOW ARE PRESENT ELEMENT NUMBERS

ELEMENTS THAT CAN NOT BE IMPACTED:
11 12 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0

ADDITIONAL STRAIN POINT	ELEMENT	S COORDINATE
1	9	0.530000D+00
2	11	0.500000D+00
3	13	0.500000D-01

EACH OF THE FOLLOWING ELEMENTS HAS A SLOPE DISCONTINUITY AT ITS FIRST NODE
12

THE GLOBAL SLOPE (RAD.) AT EACH DISCONTINUITY EQUALS:
0.463648D+00

*********** A SPATIAL FINITE ELEMENT AND HOUBOLT TEMPORAL OPERATOR PROGRAM
USED TO CALCULATE THE NONLINEAR RESPONSES OF A VARIABLE THICKNESS MULTILAYER
ARBITRARILY CURVED PARTIAL RING WITH THE FOLLOWING PARAMETERS

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```
PROPERTIES OF THE MAIN STRUCTURE:
   WIDTH OF RING (IN)                                =   0.150000D+01
   NUMBER OF ELEMENTS                                =    16
   NUMBER OF SPANWISE GAUSSIAN POINTS                =    3
   NUMBER OF DEPTHWISE GAUSSIAN POINTS               =    4
   NUMBER OF LAYERS                                  =    2
   REFERENCE SURFACE IS THE MIDDLE SURFACE OF LAYER=     1

   MATERIAL PROPERTIES OF LAYER                  =    1
        DENSITY(LB-SEC**2/IN**4)                     =   0.250000D-03
        NUMBER OF MECHANICAL SUBLAYERS               =    2

                   STRAIN          STRESS
              1   0.460000D-02   0.460000D+05
              2   0.180000D+00   0.580000D+05
         MATERIAL IS STRAIN RATE SENSITIVE WITH
                  D =    0.650000D+04 P =    0.400000D+01

   MATERIAL PROPERTIES OF LAYER                  =    2
        DENSITY(LB-SEC**2/IN**4)                     =   0.733085D-03
        NUMBER OF MECHANICAL SUBLAYERS               =    3

                   STRAIN          STRESS
              1   0.279000D-02   0.809500D+05
              2   0.225000D-01   0.105300D+06
              3   0.200000D+00   0.121000D+06
         MATERIAL IS STRAIN RATE SENSITIVE WITH
                  D =    0.404000D+02 P =    0.500000D+01
```

282

```
PROPERTIES OF BRANCH NUMBER    1  :
   WIDTH OF RING (IN)                                =   0.100000D+01
   NUMBER OF ELEMENTS                                =    2
   NUMBER OF SPANWISE GAUSSIAN POINTS                =    3
   NUMBER OF DEPTHWISE GAUSSIAN POINTS               =    4
   NUMBER OF LAYERS                                  =    1
   REFERENCE SURFACE IS THE MIDDLE SURFACE OF LAYER=     1

   MATERIAL PROPERTIES OF LAYER                  =    1
        DENSITY(LB-SEC**2/IN**4)                     =   0.733085D-03
        NUMBER OF MECHANICAL SUBLAYERS               =    3

                   STRAIN          STRESS
              1   0.279000D-02   0.809500D+05
              2   0.225000D-01   0.105300D+06
              3   0.200000D+00   0.121000D+06
         MATERIAL IS STRAIN RATE SENSITIVE WITH
                  D =    0.404000D+02 P =    0.500000D+01

   HINGED  DISPLACEMENT CONDITION AT NODE =     1
   CLAMPED DISPLACEMENT CONDITION AT NODE =    13

  CONSTRAINTS (ELASTIC FOUNDATION/SPRING) AS DESCRIBED BY INPUT
```

NODE NO	Y COORD(IN)	Z COORD(IN)	SLOPE (RAD)	RING THICKNESS(IN) LAYER 1	LAYER 2	LAYER 3
1	0.0	0.0	0.0	0.150000D+00	0.150000D+00	
2	0.100000D+01	0.0	0.0	0.140000D+00	0.140000D+00	
3	0.200000D+01	0.0	0.0	0.130000D+00	0.130000D+00	
4	0.300000D+01	0.0	0.0	0.120000D+00	0.120000D+00	
5	0.400000D+01	0.0	0.0	0.110000D+00	0.110000D+00	
6	0.500000D+01	0.0	0.0	0.100000D+00	0.100000D+00	
7	0.600000D+01	0.0	0.0	0.900000D-01	0.900000D-01	
8	0.700000D+01	0.0	0.0	0.800000D-01	0.800000D-01	
9	0.800000D+01	0.0	0.0	0.700000D-01	0.700000D-01	
10	0.900000D+01	0.0	0.0	0.600000D-01	0.600000D-01	
11	0.100000D+02	0.0	0.0	0.500000D-01	0.500000D-01	
12	0.105000D+02	0.100000D+01	0.110715D+01	0.400000D+00	0.0	
13	0.115000D+02	0.150000D+01	0.463648D+00	0.400000D+00	0.0	
14	0.108682D+02	-0.759612D-01	-0.174533D+00	0.500000D-01	0.500000D-01	
15	0.117101D+02	-0.301537D+00	-0.349066D+00	0.500000D-01	0.500000D-01	
16	0.125000D+02	-0.669873D+00	-0.523599D+00	0.500000D-01	0.500000D-01	
17	0.132139D+02	-0.116978D+01	-0.698132D+00	0.500000D-01	0.500000D-01	
18	0.138302D+02	-0.178606D+01	-0.872665D+00	0.500000D-01	0.500000D-01	
19	0.143301D+02	-0.250000D+01	-0.104720D+01	0.500000D-01	0.500000D-01	

GAUSSIAN STATIONS AND WEIGHTS:

AXG 1	=	0.112701665379259	AWG 1	=	0.277777777777778
AXG 2	=	0.500000000000000	AWG 2	=	0.444444444444444
AXG 3	=	0.887298334620741	AWG 3	=	0.277777777777778
TXG 1	=	-0.861136311594053	TWG 1	=	0.347854845137454
TXG 2	=	-0.339981043584856	TWG 2	=	0.652145154862546
TXG 3	=	0.339981043584856	TWG 3	=	0.652145154862546
TXG 4	=	0.861136311594053	TWG 4	=	0.347854845137454

SIZE OF ASSEMBLED MASS OR STIFFNESS MATRIX= 510

LUMPED MASS MATRIX FOR EACH ELEMENT:

0.108385D-03	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.108385D-03	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.249580D-05	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.197231D-05	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.105436D-03	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.105436D-03	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.241980D-05	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.194774D-05
0.101012D-03	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.101012D-03	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.226126D-05	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.183714D-05	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.980627D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.980627D-04	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.219211D-05	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.181256D-05
0.936388D-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.936388D-04	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.204016D-05	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.170197D-05	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.906896D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.906896D-04	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.197737D-05	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.167739D-05
0.862657D-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.862657D-04	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.183154D-05	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.156679D-05	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.833165D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.833165D-04	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.177461D-05	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.154221D-05
0.788926D-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.788926D-04	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.163441D-05	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.143162D-05	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.759433D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.759433D-04	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.158286D-05	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.140704D-05
0.715194D-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.715194D-04	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.144779D-05	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.129644D-05	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.685702D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.685702D-04	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.140113D-05	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.127187D-05
0.641463D-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.641463D-04	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.127070D-05	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.116127D-05	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.611970D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.611970D-04	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.122845D-05	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.113669D-05
0.567732D-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.567732D-04	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.110218D-05	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.102609D-05	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.538239D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.538239D-04	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.106384D-05	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.100152D-05

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0.4940000D-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.4940000D-04	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.941234D-06	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.890921D-06	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.464508D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.464508D-04	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.906314D-06	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.866344D-06
0.420269D-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.420269D-04	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.786890D-06	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.755747D-06	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.390776D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.390776D-04	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.754904D-06	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.731169D-06
0.143720D-03	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.139326D-03	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.763387D-05	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.375656D-05	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.140363D-03	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.142683D-03	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.433940D-05	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.375656D-05
0.156910D-03	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.154727D-03	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.433940D-05	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.375656D-05	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.155399D-03	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.156238D-03	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.433940D-05	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.375656D-05
0.326563D-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.321733D-04	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.466895D-06	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.455838D-06	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.326562D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.321732D-04	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.466882D-06	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.455837D-06
0.326592D-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.321763D-04	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.467017D-06	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.455961D-06	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.326592D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.321761D-04	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.467007D-06	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.455962D-06
0.326578D-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.321748D-04	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.466959D-06	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.455902D-06	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.326577D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.321748D-04	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.466947D-06	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.455902D-06
0.326568D-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.321737D-04	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.466916D-06	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.455855D-06	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.326565D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.321737D-04	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.466899D-06	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.455853D-06
0.326580D-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.321752D-04	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.466969D-06	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.455913D-06	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.326581D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.321750D-04	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.466959D-06	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.455915D-06
0.326578D-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.321748D-04	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.466957D-06	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.455899D-06	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.326576D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.321747D-04	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.466944D-06	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.455899D-06

C-4

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THE TRANSLATIONAL AND ROTATIONAL MASSES AT EACH NODE ARE:

0.1081851212500000D-03	0.1081851212500000D-03	0.2495796948277340D-05	0.1972314281250000D-05
0.2064478500000000D-03	0.2064478500000000D-03	0.4681056796456250D-05	0.3784877250000020D-05
0.1917015750000000D-03	0.1917015750000000D-03	0.4232268369209350D-05	0.3514528875000010D-05
0.1769553000000000D-03	0.1769553000000000D-03	0.3808908212962510D-05	0.3244180500000010D-05
0.1622090250000000D-03	0.1622090250000000D-03	0.3409020309715640D-05	0.2973832125000000D-05
0.1474627500000000D-03	0.1474627500000000D-03	0.3030648637468780D-05	0.2703483750000020D-05
0.1327164750000000D-03	0.1327164750000000D-03	0.2671837175221880D-05	0.2433135374999990D-05
0.1179702000000000D-03	0.1179702000000000D-03	0.2330627901975000D-05	0.2162787000000010D-05
0.1032239250000000D-03	0.1032239250000000D-03	0.2005070796728140D-05	0.1892438625000000D-05
0.8847765000000000D-04	0.8847765000000000D-04	0.1693203838481230D-05	0.1622090249999790D-05
0.2154541629475470D-03	0.2105766308599390D-03	0.8855670846779000D-05	0.4943571006386850D-05
0.2972726579091860D-03	0.2974102539906500D-03	0.8678801012760840D-05	0.7513127844225270D-05
0.1553988455042080D-03	0.15623811061[illegible]6660D-03	0.4339400506391720D-05	0.3756563922112610D-05
0.6531532717288260D-04	0.6434952277606980D-04	0.9338991718648730D-06	0.9117904732071850D-06
0.6531697943097550D-04	0.6435099229421580D-04	0.9339657818265250D-06	0.9118641869698770D-06
0.6531451531719330D-04	0.6434841974332530D-04	0.9338625582853540D-06	0.9117575252760850D-05
0.6531447398442260D-04	0.6434885070360640D-04	0.9338674883708430D-06	0.9117664477227460D-06
0.6531583363952980D-04	0.6434977522340470D-04	0.9339161001435950D-06	0.9118141070683050D-06
0.3265762459139650D-04	0.3217470803501760D-04	0.4669439007312950D-06	0.4558989984936540D-06

THE CONSTANTS FOR 2 ELASTIC FOUNDATIONS ARE:

THE VALUE OF THE TANGENTIAL SPRING CONSTANT IS = 0.300000D+04
THE VALUE OF THE RADIAL SPRING CONSTANT IS = 0.0
THE VALUE OF THE TORSIONAL SPRING CONSTANT IS = 0.150000D+04

FIRST ELEMENT	NUMBER OF ELEMENTS
9	2
13	3

THE ASSEMBLED MASS MATRIX:

0.100000D+01	0.0	0.100000D+01	0.0	0.0	0.249580D-05	0.0	0.0
0.0	0.197231D-05	0.0	0.0	0.0	0.0	0.206448D-03	0.0
0.0	0.0	0.0	0.0	0.206448D-03	0.0	0.0	0.0
0.0	0.0	0.0	0.468106D-05	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.378488D-05	0.0	0.0	0.0	0.0
0.191702D-03	0.0	0.0	0.0	0.0	0.0	0.191702D-03	0.0
0.0	0.0	0.0	0.0	0.0	0.423227D-05	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.351453D-05	0.0	0.0
0.0	0.0	0.176955D-03	0.0	0.0	0.0	0.0	0.0
0.176955D-03	0.0	0.0	0.0	0.0	0.0	0.0	0.380891D-05
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.324418D-05
0.0	0.0	0.0	0.0	0.162209D-03	0.0	0.0	0.0
0.0	0.0	0.162209D-03	0.0	0.0	0.0	0.0	0.0
0.0	0.340902D-05	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.297383D-05	0.0	0.0	0.0	0.0	0.147463D-03	0.0
0.0	0.0	0.0	0.0	0.147463D-03	0.0	0.0	0.0
0.0	0.0	0.0	0.303065D-05	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.270348D-05	0.0	0.0	0.0	0.0
0.132716D-03	0.0	0.0	0.0	0.0	0.0	0.132716D-03	0.0
0.0	0.0	0.0	0.0	0.0	0.267184D-05	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.243314D-05	0.0	0.0
0.0	0.0	0.117970D-03	0.0	0.0	0.0	0.0	0.0
0.117970D-03	0.0	0.0	0.0	0.0	0.0	0.0	0.233063D-05
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.216279D-05
0.0	0.0	0.0	0.0	0.103224D-03	0.0	0.0	0.0
0.0	0.0	0.103224D-03	0.0	0.0	0.0	0.0	0.0
0.0	0.200507D-05	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.189244D-05	0.0	0.0	0.0	0.0	0.884776D-04	0.0
0.0	0.0	0.0	0.0	0.884776D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.169320D-05	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.162209D-05	0.0	0.0	0.0	0.0
0.215454D-03	0.0	0.0	0.0	0.0	0.0	0.210577D-03	0.0
0.0	0.0	0.0	0.0	0.0	0.885567D-05	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.494357D-05	0.0	0.0
0.0	0.0	0.297273D-03	0.0	0.0	0.0	0.0	0.0
0.297410D-03	0.0	0.0	0.0	0.0	0.0	0.0	0.867880D-05
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.751313D-05
0.0	0.0	0.0	0.0	0.100000D+01	0.0	0.0	0.0
0.0	0.0	0.100000D+01	0.0	0.0	0.0	0.0	0.0
0.0	0.100000D+01	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.375656D-05	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.653153D-04	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.643495D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.933899D-06	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.911798D-06	0.0	0.0	0.0	0.0
0.653170D-04	0.0	0.0	0.0	0.0	0.0	0.643510D-04	0.0
0.0	0.0	0.0	0.0	0.0	0.933966D-06	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.911864D-06	0.0	0.0
0.0	0.0	0.653145D-04	0.0	0.0	0.0	0.0	0.0
0.643484D-04	0.0	0.0	0.0	0.0	0.0	0.0	0.933863D-06
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.911758D-06
0.0	0.0	0.0	0.0	0.653145D-04	0.0	0.0	0.0
0.0	0.0	0.643489D-04	0.0	0.0	0.0	0.0	0.0
0.0	0.933867D-06	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.911766D-06	0.0	0.0	0.0	0.0	0.653158D-04	0.0
0.0	0.0	0.0	0.0	0.643498D-04	0.0	0.0	0.0
0.0	0.0	0.0	0.933916D-06	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.911814D-06	0.0	0.0	0.0	0.0
0.326576D-04	0.0	0.0	0.0	0.0	0.0	0.321747D-04	0.0
0.0	0.0	0.0	0.0	0.0	0.466944D-06	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.455899D-06		

THE ASSEMBLED STIFFNESS MATRIX:

0.1000000D+01	0.0	0.100000D+01	0.0	0.0	0.621850D+06	0.0	0.0
0.481058D+06	0.115092D+07	0.0	0.0	0.953121D+06	-0.819301D+06	0.196632D+08	0.0
0.0	-0.917719D+06	-0.940935D+06	-0.146232D+06	0.320683D+07	0.0	0.0	0.295868D+06
0.459877D+06	-0.170604D+07	-0.113949D+06	0.106461D+07	0.0	0.0	-0.455670D+06	-0.282854D+06
-0.117043D+06	0.170778D+07	-0.162480D+05	0.218480D+07	-0.948048D+07	0.705048D+05	0.828649D+06	-0.760780D+06
0.182587D+08	0.705048D+05	-0.143246D+07	-0.742701D+06	-0.817334D+06	-0.135787D+06	0.257007D+07	0.758145D+06
0.689763D+06	0.238875D+06	0.398902D+06	-0.147103D+07	-0.982679D+05	0.852662D+06	0.819301D+06	-0.770331D+06
-0.394895D+06	-0.263347D+06	-0.117043D+06	0.147277D+07	-0.150875D+05	0.202875D+07	-0.877823D+07	0.652823D+05
0.712882D+06	-0.702258D+06	0.168542D+08	0.652823D+05	-0.113760D+07	-0.591495D+06	-0.702437D+06	-0.125342D+05
0.202370D+07	0.647600D+06	0.546107D+06	0.189721D+06	0.342079D+06	-0.125342D+07	-0.837484D+05	0.670917D+06
0.760780D+06	-0.658916D+06	-0.338452D+06	-0.243840D+06	-0.117043D+06	0.125516D+07	-0.139269D+05	0.187269D+07
-0.807597D+07	0.600597D+05	0.605819D+06	-0.643737D+06	0.154497D+08	0.600597D+05	-0.886299D+06	-0.462359D+06
-0.596245D+05	-0.114897D+06	0.156137D+07	0.545760D+06	0.423940D+06	0.147828D+06	0.289708D+06	-0.105322D+07
-0.703965D+05	0.517049D+06	0.702258D+06	-0.556205D+06	-0.286372D+06	-0.224332D+06	-0.117043D+06	0.105496D+07
-0.127663D+05	0.171663D+07	-0.737371D+07	0.548371D+05	0.507461D+06	-0.585215D+06	0.140452D+08	0.548371D+05
-0.675069D+06	-0.353550D+06	-0.498756D+06	-0.104452D+06	0.117550D+07	0.452624D+06	0.321520D+06	0.112613D+06
0.241689D+06	-0.870430D+06	-0.581741D+05	0.388735D+06	0.643737D+06	-0.462198D+06	-0.238643D+06	-0.204825D+06
-0.1[illegible]043D+06	0.872171D+06	-0.116057D+05	0.156057D+07	-0.667145D+07	0.476145D+05	0.417806D+06	-0.526694D+06
0.126406D+08	0.496145D+05	-0.500429D+06	-0.263325D+06	-0.409973D+06	-0.940065D+05	0.859321D+06	0.368192D+06
0.237103D+06	0.834967D+05	0.198023D+06	-0.705048D+06	-0.471593D+05	0.283653D+06	0.585215D+06	-0.376896D+06
-0.195266D+06	-0.185318D+06	-0.117043D+06	0.706789D+06	-0.104452D+05	0.140452D+07	-0.596919D+07	0.443919D+05
0.336856D+06	-0.468172D+06	0.112361D+08	0.443919D+05	-0.358893D+06	-0.189944D+06	-0.329893D+06	-0.835613D+05
0.605869D+06	0.292465D+06	0.168949D+06	0.598977D+05	0.158708D+06	-0.557075D+06	-0.372860D+05	0.199478D+06
0.526694D+06	-0.300298D+06	-0.156242D+06	-0.165811D+06	-0.117047D+06	0.558816D+06	-0.928459D+04	0.124846D+07
-0.526694D+07	0.391694D+05	0.264611D+06	-0.409651D+06	0.783161D+07	0.391694D+05	-0.246977D+06	-0.131663D+06
-0.258518D+06	-0.731161D+05	0.408172D+06	0.225441D+06	0.115314D+06	0.412353D+05	0.123746D+06	-0.426511D+06
-0.285744D+05	0.133889D+06	0.468172D+06	-0.232405D+06	-0.121570D+06	-0.146304D+06	-0.117041D+06	0.478252D+06
-0.812471D+04	0.109240D+07	-0.456468D+07	0.339468D+05	0.201069D+06	-0.351129D+06	0.842710D+07	0.339468D+05
-0.161195D+06	-0.857394D+05	-0.195947D+06	-0.626710D+05	0.259260D+06	0.167123D+06	0.744559D+05	0.269288D+05
0.931360D+05	-0.313355D+06	-0.210242D+05	0.845615D+05	0.409651D+06	-0.173216D+06	-0.912501D+05	-0.126797D+06
-0.117043D+06	0.315096D+06	-0.696344D+04	0.936344D+06	-0.386242D+07	0.287242D+05	0.146232D+06	-0.272608D+06
0.114310D+08	0:287242D+05	-0.980646D+05	-0.534317D+05	-0.141880D+06	0.408169D+07	0.104788D+08	0.117508D+06
0.446329D+05	0.163973D+05	0.668780D+05	-0.121925D+07	0.211064D+05	0.735026D+06	0.351129D+06	-0.122731D+06
-0.652823D+05	-0.107289D+06	0.475886D+06	0.126919D+07	-0.413499D+05	0.248527D+07	-0.557075D+07	-0.111415D+08
0.417807D+06	-0.116057D+07	0.209071D+08	0.118842D+07	-0.594224D+06	-0.831899D+06	-0.466784D+00	-0.534137D+07
0.666343D+07	-0.664351D+06	0.332176D+06	0.326639D+06	0.260940D+00	0.445660D+06	-0.148553D+06	0.110725D+07
0.519025D+06	0.103805D+07	-0.389266D+05	-0.432520D+06	-0.232114D+06	-0.676343D+06	-0.435721D-09	0.346016D+07
0.0	0.0	0.0	0.0	0.100000D+01	0.0	0.0	0.0
0.0	0.0	0.100000D+01	0.0	0.0	0.0	0.0	0.0
0.0	0.100000D+01	0.928460D+06	-0.696343D+06	-0.260940D+00	-0.432520D+06	0.0	0.0
0.0	0.173008D+07	-0.401252D+07	0.361558D+06	0.179928D+06	-0.284487D+06	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.802833D+07	-0.361522D+06
-0.882711D+05	-0.367133D+05	-0.160243D+06	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.614317D+02	0.299376D+06	0.179926D+06	0.3669[illegible]0D+05	0.120215D+05
0.624893D+05	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	-0.341627D+06	-0.389889D+00	0.670233D+05	0.284480D+06	-0.160245D+06	-0.625094D+05	-0.863851D+05
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.302640D+00	0.216811D+06	0.172878D+02	0.691111D+06	-0.401215D+07	0.361455D+06	0.179914D+06	-0.284483D+06
0.802812D+07	-0.361556D+06	-0.882424D+05	-0.367009D+05	-0.160234D+06	0.370013D+02	0.299378D+06	0.179916D+06
0.366955D+05	0.120203D+05	0.624910D+05	-0.341624D+06	0.131675D+02	0.670246D+05	0.284486D+06	-0.160231D+06
-0.625088D+05	-0.863929D+05	0.118246D+01	0.216800D+06	0.163887D+02	0.691129D+06	-0.401233D+07	0.361521D+06
0.179921D+06	-0.284486D+06	0.802843D+07	-0.361524D+08	-0.882561D+05	-0.367078D+05	-0.160238D+06	-0.125260D+07
0.299420D+06	0.179920D+06	0.366962D+05	0.120209D+05	0.624899D+05	-0.341635D+06	0.236418D+02	0.670283D+05
0.284482D+06	-0.160239D+06	-0.625094D+05	-0.863892D+05	0.112076D+02	0.216806D+06	0.231346D+02	0.691104D+06
-0.401247D+07	0.361653D+06	0.179730D+06	-0.284494D+06	0.802844D+07	-0.361418D+06	-0.882670D+05	-0.367184D+05
-0.160238D+05	-0.328683D+02	0.299363D+06	0.179921D+06	0.366916D+05	0.120213D+05	0.624877D+05	-0.341627D+06
0.103683D+02	0.670213D+05	0.284474D+06	-0.160247D+06	-0.625113D+05	-0.863862D+05	0.595809D+01	0.216820D+06
0.207911D+02	0.691101D+06	-0.401230D+07	0.361449D+06	0.179918D+06	-0.284481D+06	0.802826D+07	-0.361588D+06
-0.892535D+05	-0.367028D+05	-0.160239D+06	0.400670D+02	0.299400D+06	0.179921D+06	0.366998D+05	0.120208D+05
0.624911D+05	-0.341629D+06	0.100361D+02	0.670266D+05	0.284487D+06	-0.160235D+06	-0.625082D+05	-0.863899D+05
0.111944D+01	0.216802D+06	0.166096D+02	0.691118D+06	-0.401234D+07	0.361548D+06	0.179923D+06	-0.284488D+06
0.401417D+07	-0.361497D+06	-0.882568D+05	-0.367097D+05	-0.160237D+06	0.340680D+06	0.149689D+06	0.179920D+06
0.366946D+05	0.120209D+05	0.624895D+05	-0.170814D+06	-0.673799D+05	0.335066D+05	0.284480D+06	-0.160240D+06
-0.625098D+05	-0.863890D+05	-0.307984D+06	0.108406D+06	-0.550058D+05	0.345555D+06		

HIGHEST NATURAL FREQUENCY (RAD/SEC) = 0.981252170+06

DELTAT SHOULD BE EQUAL TO OR LESS THAN 0.200000D-05

TIME STEP SIZE USED IN PRUGRAM (SEC)= 0.200000D-05

FRAGMENT PROPERTIES

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NO. OF FRAGMENTS                                   =    1
EFFECTIVE LENGTH OF IMPACT (IN) ON MAIN STRUCTURE =    0.400000D+00

  FRAG. NO.                            =    1
  DIAMETER  (IN)                       =    0.1000000D+01
  WEIGHT(LBS-SEC**2/IN.)               =    0.385610D-03
  MOMENT OF INERTIA(IN-LB-SEC**2)      =    0.482014D-04
   CG Y COORDINATE    (IN)             =    0.600000D+01
   CG Z COORDINATE    (IN)             =   -0.200000D+01
  ANGULAR ROTATION (DEG)               =    0.0
  VEL IN Y DIR (IN/SEC)                =    0.260796D+04
  VEL IN Z DIR (IN/SEC)                =    0.148275D+04
   ANGULAR VEL (DEG/SEC)               =    0.0
  COEFF OF RESTITUTION                 =    0.100000D+01
  COEFF OF FRICTION                    =    0.0
  INITIAL KINETIC ENERGY (IN-LB)       =    0.173525D+04
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THE TPAIN FOR EACH FRAGMENT IS: 0.960000D-03

THE FOLLOWING IS THE TIME SOLUTION OF THE FRAGMENT- RING IMPACT
OUTPUT WILL BE PRINTED EVERY 20 CYCLES USINGOUTPUT OPTION 3.
REACTION FORCES APPLIED TO THE STRUCTURE WILL BE PRINTED AT EACH OUTPUT CYCLE
FOR NODES AT WHICH BOUNDARY CONDITIONS ARE SPECIFIED. D.O.F. THAT ARE
NOT RESTRAINED AT THAT NODE WILL HAVE A REACTION FORCE = 0.0.
ALL IMPACTS WILL BE DESIGNATED AND ALL THE FRAGMENT ENERGICS WILL BE
LISTED AFTER EACH IMPACT.

ORIGINAL PAGE IS
OF POOR QUALITY

IMPACT NO. 1 TIME 0.966000D-03 DURING CYCLE 484 ELEM 9 FRAG 1 DISTANCE 0.524505D+00
FRAG 1 TC= 0.1361D+04 RF= 0.0 TOE= 0.1361D+04 FRAG

CYCLE= 490

ELEMENT	SI STA 1	SO STA 1	SI STA 2	SO STA 2	SI STA 3	SO STA 3
1	0.74534499D-07	-0.35510519D-07	0.18297507D-07	0.63840875D-07	-0.21954007D-06	-0.26566986D-07
	0.19511990D-07	0.0	0.41069191D-07	0.0	-0.12305353D-06	0.0
2	0.10219743D-06	-0.32601344D-06	-0.20753801D-06	0.31699906D-07	-0.21103042D-05	-0.12412288D-05
	-0.11190800D-06	0.0	-0.87919052D-07	0.0	-0.16757665D-05	0.0
3	-0.18353409D-05	-0.25653355D-05	-0.33437826D-05	-0.32443108D-05	-0.10497115D-04	-0.96182171D-05
	-0.22003382D-05	0.0	-0.32940467D-05	0.0	-0.10057666D-04	0.0
4	-0.16131788D-04	-0.15521684D-04	-0.24989156D-04	-0.24403137D-04	-0.33659480D-04	-0.33097262D-04
	-0.15826736D-04	0.0	-0.24696147D-04	0.0	-0.33378371D-04	0.0
5	-0.36978186D-04	-0.85708697D-04	-0.10062018D-03	-0.56647952D-04	-0.15524489D-03	-0.25280812D-04
	-0.61343441D-04	0.0	-0.78634068D-04	0.0	-0.90262849D-04	0.0
6	0.89578394D-04	-0.31985044D-03	-0.50205709D-04	0.92464174D-04	-0.81119103D-03	-0.16013095D-03
	-0.11513602D-03	0.0	0.21129232D-04	0.0	-0.48566099D-03	0.0
7	-0.10897450D-02	0.10803838D-02	0.15510782D-02	-0.10159575D-02	0.42513842D-02	-0.26297411D-02
	-0.46805814D-05	0.0	0.26756034D-03	0.0	0.81082154D-03	0.0
8	0.36723105D-02	-0.17684892D-02	0.53510987D-03	-0.15908405D-03	-0.15912327D-02	0.19985445D-02
	0.95191063D-03	0.0	0.18801291D-03	0.0	0.20365589D-03	0.0
9	-0.85699772D-03	0.74257972D-03.	-0.18049902D-02	0.25833928D-02	-0.48025834D-02	0.20316363D-02
	-0.57158996D-04	0.0	0.38920129D-03	0.0	-0.13854736D-02	0.0
10	-0.49718296D-02	0.53355814D-02	0.18747160D-02	0.42063151D-03	0.44640963D-02	-0.71905422D-02
	0.18187593D-03	0.0	0.11476738D-02	0.0	-0.13632229D-02	0.0
11	0.13969542D-02	-0.44870764D-04	0.12787932D-03	-0.56976147D-03	-0.10915314D-03	-0.62611332D-04
12	-0.79228070D-04	0.17933362D-03	-0.16051046D-03	-0.97554651D-04	-0.28120653D-05	-0.13546190D-03
13	0.10249893D-02	0.33108227D-03	0.30145404D-03	0.15651048D-03	0.54923508D-04	0.46784351D-03
	0.67833578D-03	0.0	0.22898226D-03	0.0	0.26138351D-03	0.0
14	0.23156865D-03	0.45199967D-04	0.15103077D-03	0.87832320D-04	0.44204607D-04	0.10334494D-03
	0.13838431D-03	0.0	0.11943155D-03	0.0	0.73774774D-04	0.0
15	0.21720252D-04	0.31887313D-04	0.13036570D-04	0.15327861D-04	0.76049830D-05	0.20949883D-05
	0.26803782D-04	0.0	0.14182216D-04	0.0	0.48499857D-05	0.0
16	0.12677956D-05	0.29449982D-05	-0.48257495D-05	-0.44755272D-05	-0.34786871D-05	-0.42833651D-05
	0.21163969D-05	0.0	-0.46506383D-05	0.0	-0.38810261D-05	0.0
17	-0.20985399D-05	-0.21425209D-05	-0.22261834D-05	-0.23150227D-05	-0.15808859D-05	-0.16992422D-05
	-0.21205304D-05	0.0	-0.22706030D-05	0.0	-0.16400640D-05	0.0
18	-0.95149317D-06	-0.93969521D-06	-0.31331858D-06	-0.30491162D-06	-0.43277866D-06	-0.44292738D-06
	-0.94559419D-06	0.0	-0.30911510D-06	0.0	-0.43785302D-06	0.0

CYCLE= 490

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.19584390D-02	0.26216555D-02	-0.19703802D-02	0.26182280D-02
	0.26323759D-03	0.0		
2	0.12787932D-03	-0.56976147D-03	0.12787115D-03	-0.56992387D-03
3	0.11961516D-02	0.41420744D-03	0.11954370D-02	0.41412169D-03
	0.80517950D-03	0.0		

ENERGY AND WORK AT THE END OF TIME CYCLE 490

FRAGMENT	KINETIC ENERGY
1	0.136119D+04

J= 490 TIME (SEC.) = 0.980000D-03 TIME AFTER INITIAL IMPACT = 0.140000D-04
WORK INPUT INTO RING (IN.-LB.) = 0.374054D+03
RING KINETIC ENERGY (IN.-LB.) = 0.346430D+03
RING ELASTIC ENERGY (IN.-LB.) = 0.229818D+02
RING PLASTIC WORK (IN.-LB.) = 0.177300D+01
ENERGY STORED IN THE ELASTIC RESTRAINTS (IN.-LB.) = 0.869296D+00

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	0.0	-0.5197D-07	0.1757D-07	0.0	0.0	0.3956D+00	0.5033D-01	0.3718D-07	-0.4125D-07
2	-0.2133D-07	-0.1718D-07	-0.2090D-06	-0.2643D-06	0.1000D+01	-0.1718D-07	-0.4643D+00	-0.1166D-01	-0.2396D-06	-0.3384D-06
3	-0.6142D-06	-0.1468D-06	-0.1095D-05	-0.2702D-05	0.2000D+01	-0.1468D-06	-0.2401D+02	-0.2219D+01	-0.2706D-05	-0.2690D-05
4	-0.5505D-05	-0.7459D-06	-0.1493D-05	-0.1337D-04	0.3000D+01	-0.7459D-06	-0.1657D+03	-0.1411D+02	-0.1347D-04	-0.1304D-04
5	-0.3030D-04	-0.3517D-05	-0.4041D-05	-0.3601D-04	0.4000D+01	-0.3517D-05	-0.4503D+03	-0.3127D+02	-0.3123D-04	-0.5034D-04
6	-0.1179D-03	-0.1905D-04	-0.2134D-03	-0.1310D-03	0.5000D+01	-0.1905D-04	0.2141D+03	0.2545D+02	-0.1045D-03	-0.2106D-03
7	-0.3381D-03	-0.8631D-06	-0.9643D-03	-0.9521D-03	0.6000D+01	-0.8631D-06	-0.2249D+03	-0.1629D+03	-0.1227D-02	-0.1226D-03
8	0.6328D-03	0.7089D-03	0.1414D-01	0.2972D-02	0.7001D+01	0.7089D-03	0.4540D+03	-0.5981D+01	0.4012D-02	0.2702D-03
9	0.9756D-03	0.2358D-01	0.1876D-01	-0.1000D-02	0.8001D+01	0.2358D-01	0.3514D+04	-0.3185D+03	-0.1166D-07	0.2025D-03
10	-0.3988D-03	0.3023D-01	-0.1499D-01	-0.4250D-02	0.9000D+01	0.3023D-01	0.3124D+04	0.9251D+02	-0.5473D-02	-0.9695D-04
11	-0.4694D-03	0.1713D-03	-0.1774D-02	0.1129D-02	0.1000D+02	0.1713D-03	-0.2564D+04	-0.2699D+03	0.1736D-02	-0.4752D-03
12	0.7594D-04	-0.1551D-04	0.1760D-03	0.1471D-03	0.1050D+02	0.1000D+01	-0.1498D+04	0.2435D+02	0.7476D-04	0.2194D-03
13	0.0	0.0	0.0	-0.6817D-05	0.1150D+02	0.1500D+01	0.6183D+03	0.2009D+02	0.4058D-04	-0.5421D-04
14	-0.1232D-03	0.3217D-04	-0.5308D-03	0.1985D-03	0.1087D+02	-0.7591D-01	0.3269D+03	0.1089D+07	0.1765D-03	0.2651D-03
15	-0.7278D-05	0.2392D-05	0.2279D-04	0.2772D-04	0.1171D+02	-0.3015D+00	0.4232D+02	0.1619D+01	0.2103D-04	0.4780D-04
16	0.4896D-05	0.7092D-06	0.2614D-05	0.4946D-05	0.1250D+02	-0.6699D+00	-0.1348D+02	-0.4943D+00	0.5302D-05	0.3877D-05
17	0.2449D-05	0.2059D-06	-0.8109D-06	-0.1925D-05	0.1321D+02	-0.1170D+01	-0.6676D+01	-0.2500D+00	-0.1853D-05	-0.2138D-05
18	0.6601D-06	0.2202D-07	-0.7281D-07	-0.1278D-05	0.1383D+02	-0.1786D+01	-0.9015D+00	-0.3335D-01	-0.1270D-05	-0.1299D-05
19	0.2012D-06	-0.8806D-08	-0.1094D-06	-0.6139D-06	0.1433D+02	-0.2500D+01			-0.6116D-06	-0.6208D-06

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUV =	FRWV =	FRAV =
1	0.855580D+01	-0.560546D+00	0.0	0.260796D+04	0.508411D+03	0.0

REACTIONS AT NODE	RV(LBS)	RW(LBS)	RM(IN-LBS)
1	-0.135568D+00	0.539785D-01	0.0
13	-0.103512D+04	-0.174652D+03	0.733247D+02

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.533558D-02	10	2	1	0.980000D-03
2	0.139695D-02	11	1	1	0.980000D-03
INTERFACE	0.114767D-02	10	1	2	0.980000D-03

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.262166D-02	9	1	0.980000D-03	2
2	0.127879D-03	11	2	0.980000D-03	1
INTERFACE	0.950723D-03	9	1	0.974000D-03	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.401169D-02	8	1	0.980000D-03
2	0.219403D-03	12	2	0.980000D-03

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CYCLE= 510

ELEMENT	SI STA 1	SO STA 1	SI STA 2	SO STA 2	SI STA 3	SO STA 3
1	0.89778700D-03	-0.92091097D-04	0.44835594D-03	0.19687018D-03	0.56181035D-04	0.50502003D-03
	0.40294795D-03	0.0	0.32261306D-03	0.0	0.28060153D-03	0.0
2	0.10455651D-03	0.49413371D-03	0.47242025D-03	0.36221626D-03	0.74211864D-03	0.16018627D-03
	0.29334511D-03	0.0	0.41731825D-03	0.0	0.45115245D-03	0.0
3	0.50067480D-03	0.41820860D-03	0.64097145D-04	0.52202544D-03	-0.65346348D-04	0.89964299D-03
	0.45944170D-03	0.0	0.29306129D-03	0.0	0.41714832D-03	0.0
4	0.60306373D-03	0.10335428D-03	0.11249206D-02	0.25007543D-03	0.99223462D-03	-0.23138185D-03
	0.35320901D-03	0.0	0.68749800D-03	0.0	0.38042638D-03	0.0
5	0.86266728D-04	0.75033526D-03	-0.62528107D-03	0.70109324D-03	-0.83970009D-03	0.10983783D-02
	0.41830100D-03	0.0	0.37906083D-04	0.0	0.12933909D-03	0.0
6	-0.34583126D-03	0.71362475D-03	0.63483321D-03	0.22669414D-03	0.14738942D-02	-0.28556120D-03
	0.18389675D-03	0.0	0.43076367D-03	0.0	0.59416648D-03	0.0
7	0.27214278D-02	-0.82515651D-03	0.61652868D-02	-0.28949719D-02	0.95773863D-02	-0.44803064D-02
	0.94813567D-03	0.0	0.16351575D-02	0.0	0.25486899D-02	0.0
8	0.84534705D-02	-0.39530859D-02	0.19519562D-02	-0.45552197D-03	-0.33499175D-02	0.32720014D-02
	0.22501923D-02	0.0	0.74821713D-03	0.0	-0.38908040D-04	0.0
9	-0.50512666D-02	0.33419239D-02	-0.12331119D-01	0.79029505D-02	-0.18832896D-01	0.11774746D-01
	-0.85467134D-03	0.0	-0.22140844D-02	0.0	-0.35290750D-02	0.0
10	-0.92748697D-02	0.54819049D-02	0.69327896D-02	-0.16895100D-02	0.98366749D-02	-0.19008810D-01
	-0.18964824D-02	0.0	0.26216398D-02	0.0	-0.45860674D-02	0.0
11	0.24096232D-02	-0.61820535D-03	0.91082726D-03	-0.15991010D-02	0.87220298D-03	-0.11198271D-02
12	0.84835171D-03	-0.63627174D-03	0.38130525D-03	-0.56662390D-03	0.17920305D-03	-0.23203152D-03
13	0.14408991D-02	0.10008573D-02	0.11562738D-02	0.31820283D-03	0.14208556D-02	0.19188345D-03
	0.12208782D-02	0.0	0.73723829D-03	0.0	0.80636955D-03	0.0
14	0.14840769D-02	0.24759386D-03	0.10236179D-02	0.36380001D-03	0.51988308D-03	0.43271940D-03
	0.86583536D-03	0.0	0.69370898D-03	0.0	0.47630124D-03	0.0
15	0.21272463D-03	0.78829849D-03	0.29455785D-03	0.47887844D-03	0.45721502D-03	0.25265666D-03
	0.50051156D-03	0.0	0.38671815D-03	0.0	0.35493584D-03	0.0
16	0.35535289D-03	0.36455334D-03	0.34789679D-03	0.23947460D-03	0.14343030D-03	0.32187917D-03
	0.35999531D-03	0.0	0.19368569D-03	0.0	0.23265474D-03	0.0
17	0.26480414D-03	0.15535443D-04	0.11772163D-03	0.11846001D-03	-0.65549908D-04	0.18448497D-03
	0.14016979D-03	0.0	0.11809082D-03	0.0	0.59467531D-04	0.0
18	-0.42315404D-04	0.99215497D-04	0.18079417D-03	-0.58735582D-04	0.42373976D-03	-0.19761195D-03
	0.28450047D-04	0.0	0.61029296D-04	0.0	0.11306391D-03	0.0

CYCLE= 510

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.12949126D-01	0.81409036D-02	-0.13034070D-01	0.81080335D-02
	-0.26952794D-02	0.0		
2	0.91082726D-03	-0.15991010D-02	0.91041283D-03	-0.16003816D-02
3	0.15319586D-02	0.11570263D-02	0.15307870D-02	0.11563577D-02
	0.13444925D-02	0.0		

ENERGY AND WORK AT THE END OF TIME CYCLE 510

FRAGMENT	KINETIC ENERGY
1	0.136119D+04

J= 510 TIME (SEC.) = 0.102000D-02 TIME AFTER INITIAL IMPACT = 0.540000D-04
WORK INPUT INTO RING (IN.-LB.) = 0.374054D+03
RING KINETIC ENERGY (IN.-LB.) = 0.219816D+03
RING ELASTIC ENERGY (IN.-LB.) = 0.875899D+02
RING PLASTIC WORK (IN.-LB.) = 0.576374D+02
ENERGY STORED IN THE ELASTIC RESTRAINTS (IN.-LB.) = 0.901086D+01

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	0.0	-0.8277D-03	0.7360D-03	0.0	0.0	0.2478D+04	0.2248D+03	0.8881D-03	0.2822D-03
2	0.3986D-03	0.1346D-03	0.3949D-04	0.1142D-03	0.1000D+01	0.1346D-03	0.3191D+04	0.3043D+03	0.4006D-04	0.3365D-03
3	0.8180D-03	-0.1141D-04	0.4477D-03	0.6235D-03	0.2001D+01	-0.1141D-04	0.2552D+04	0.2946D+03	0.6838D-03	0.4438D-03
4	0.1079D-02	-0.1665D-04	-0.1384D-02	0.2306D-03	0.3001D+01	-0.1665D-04	0.3909D+04	0.2416D+03	0.1865D-03	0.3667D-03
5	0.1805D-02	0.1350D-03	0.2420D-02	0.4981D-03	0.4002D+01	0.1350D-03	0.1226D+04	0.2130D+03	0.5548D-03	0.3402D-03
6	0.1644D-02	0.9934D-04	-0.3896D-02	-0.2882D-03	0.5002D+01	0.9934D-04	0.2118D+04	0.1201D+03	-0.5065D-03	0.3973D-03
7	0.2135D-02	-0.4338D-02	-0.1748D-02	0.1159D-02	0.6002D+01	-0.4338D-02	0.2643D+04	-0.3577D+03	0.1409D-02	0.4154D-03
8	0.5774D-02	0.1339D-01	0.5155D-01	0.5504D-02	0.7006D+01	0.1339D-01	0.1997D+04	0.2806D+01	0.8780D-02	0.1052D-02
9	0.4689D-02	0.8643D-01	0.6760D-01	-0.4683D-02	0.8005D+01	0.8643D-01	0.2271D+04	0.6234D+03	-0.3246D-02	0.1888D-03
10	-0.3611D-02	0.9658D-01	-0.8805D-01	-0.1509D-01	0.8996D+01	0.9658D-01	0.4721D+04	0.4141D+01	-0.1457D-01	-0.6896D-03
11	-0.7073D-02	0.3893D-02	-0.9665D-02	0.1484D-02	0.9993D+01	0.3893D-02	-0.3994D+04	-0.9710D+03	0.2818D-02	-0.1928D-02
12	0.6899D-03	0.8829D-03	-0.2650D-02	0.2104D-03	0.1050D+02	0.1001D+01	-0.1075D+04	-0.3667D+03	0.6492D-03	-0.2213D-03
13	0.0	0.0	0.0	0.4242D-04	0.1150D+02	0.1500D+01	0.1858D+04	0.5231D+02	0.1062D-03	-0.2134D-04
14	-0.6104D-02	-0.3169D-02	-0.2369D-02	0.1277D-02	0.1086D+02	-0.7802D-01	0.1795D+04	0.5351D+02	0.1452D-02	0.7654D-03
15	-0.4778D-02	-0.2715D-02	0.3399D-02	0.3584D-03	0.1170D+02	-0.3025D+00	0.1197D+04	0.4821D+02	0.3162D-03	0.5084D-03
16	-0.4081D-02	-0.1865D-02	0.1785D-02	0.4515D-03	0.1250D+02	-0.6694D+00	0.5994D+03	0.2412D+02	0.4739D-03	0.3911D-03
17	-0.3627D-02	-0.1190D-02	0.9746D-03	0.2281D-03	0.1321D+02	-0.1168D+01	0.3458D+03	0.1287D+02	0.2360D-03	0.2066D-03
18	-0.3382D-02	-0.5391D-03	0.9699D-03	-0.5372D-04	0.1383D+02	-0.1784D+01	0.9318D+02	-0.1335D+01	-0.8916D-04	0.5452D-04
19	-0.3200D-02	0.1739D-04	0.3062D-02	0.3235D-03	0.1433D+02	-0.2497D+01			0.4198D-03	0.5355D-04

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUV =	FRWV =	FRAV =
1	0.866012D+01	-0.540209D+00	0.0	0.260796D+04	0.508411D+03	0.0

REACTIONS AT NODE	RV(LBS)	RW(LBS)	RM(IN-LBS)
1	-0.252403D+04	-0.343900D+03	0.0
13	-0.562811D+03	0.479654D+03	0.987197D+02

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.117747D-01	9	2	3	0.102000D-02
2	0.257420D-02	11	1	1	0.101400D-02
INTERFACE	0.309256D-02	10	1	2	0.100600D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.814090D-02	9	1	0.102000D-02	2
2	0.929835D-03	11	2	0.101800D-02	1
INTERFACE	0.134449D-02	13	3	0.102000D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.878026D-02	8	1	0.102000D-02
2	0.649213D-03	12	1	0.102000D-02

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CYCLE= 530

ELEMENT	SI (STA 1)	SO (STA 1)	SI (STA 2)	SO (STA 2)	SI (STA 3)	SO (STA 3)
1	0.14474656D-02	-0.19846690D-03	0.12594775D-02	-0.10942719D-03	0.12061690D-02	0.10367656D-03
	0.62549937D-03	0.0	0.57502515D-03	0.0	0.65492277D-03	0.0
2	0.13936140D-02	-0.19686511D-03	0.10225971D-02	0.32749766D-03	0.23655728D-03	0.38800784D-03
	0.59837446D-03	0.0	0.67504741D-03	0.0	0.31228256D-03	0.0
3	-0.47249727D-03	0.11381322D-02	-0.22920836D-03	0.50565404D-03	0.54905416D-03	0.45941932D-03
	0.33281745D-03	0.0	0.13822284D-03	0.0	0.50423674D-03	0.0
4	0.11953843D-02	-0.41177405D-03	0.46771583D-03	0.44190640D-03	-0.74229141D-03	0.71026130D-03
	0.39180512D-03	0.0	0.45481112D-03	0.0	-0.16015059D-04	0.0
5	-0.15974426D-02	0.16578126D-02	-0.14109660D-02	0.11484402D-02	-0.87937497D-03	0.10269733D-02
	0.30185003D-04	0.0	-0.13126289D-03	0.0	0.73799145D-04	0.0
6	0.67840590D-03	-0.12171313D-03	0.40679524D-02	-0.20519227D-02	0.69854046D-02	-0.40179169D-02
	0.27834639D-03	0.0	0.10080149D-02	0.0	0.14837438D-02	0.0
7	0.75310712D-02	-0.43687724D-02	0.68572766D-02	-0.40341807D-02	0.64294238D-02	-0.34982827D-02
	0.15811494D-02	0.0	0.14115480D-02	0.0	0.14655706D-02	0.0
8	0.47376981D-02	-0.29588300D-02	-0.12022769D-02	0.29900932D-03	-0.68345701D-02	0.29536168D-02
	0.88943405D-03	0.0	-0.45163378D-03	0.0	-0.19404767D-02	0.0
9	-0.10207965D-01	0.58080404D-02	-0.17427290D-01	0.85156143D-02	-0.21883023D-01	0.12696477D-01
	-0.21999622D-02	0.0	-0.44558379D-02	0.0	-0.45932728D-02	0.0
10	-0.87823212D-02	0.29949217D-02	0.81174464D-02	-0.39779552D-02	0.10052994D-01	-0.22662045D-01
	-0.28936998D-02	0.0	0.20697456D-02	0.0	-0.63045253D-02	0.0
11	0.13100209D-02	-0.54835853D-03	0.82278118D-03	-0.11904063D-02	0.10092492D-02	-0.11587472D-02
12	0.13307427D-02	-0.12483352D-02	0.17678882D-02	-0.18487843D-02	0.23139123D-02	-0.23403548D-02
13	-0.29879310D-03	0.13803653D-02	-0.65625648D-03	-0.66711021D-03	0.96819461D-03	-0.69066038D-03
	0.54078598D-03	0.0	-0.66168334D-03	0.0	0.13876711D-03	0.0
14	0.22297470D-02	-0.20177964D-02	0.13952115D-02	-0.12728158D-02	0.39631616D-03	-0.70953346D-03
	0.10597533D-03	0.0	0.61197829D-04	0.0	-0.15660865D-03	0.0
15	-0.13701968D-03	-0.39621056D-03	-0.33395657D-03	-0.23770932D-03	-0.52719359D-03	-0.74769027D-04
	-0.26661512D-03	0.0	-0.28543295D-03	0.0	-0.30098131D-03	0.0
16	-0.52282029D-03	-0.86005457D-04	-0.35857811D-03	-0.12324820D-03	-0.20436643D-03	-0.16971899D-03
	-0.30441288D-03	0.0	-0.24091315D-03	0.0	-0.18704271D-03	0.0
17	-0.10144204D-03	-0.21311149D-03	-0.36625414D-04	-0.16779981D-03	-0.41685869D-04	-0.19437490D-03
	-0.15727677D-03	0.0	-0.10221261D-03	0.0	-0.11803039D-03	0.0
18	-0.12995744D-03	0.56611958D-05	-0.12838142D-03	0.32801007D-05	-0.12196241D-03	0.64456563D-05
	-0.62148121D-04	0.0	-0.62550659D-04	0.0	-0.57758378D-04	0.0

CYCLE= 530

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.17968640D-01	0.86893541D-02	-0.18133044D-01	0.86519262D-02
	-0.50076824D-02	0.0		
2	0.82278118D-03	-0.11904063D-02	0.82244297D-03	-0.11911157D-02
3	-0.78645508D-04	0.18780701D-02	-0.78648601D-04	0.18763098D-02
	0.89971228D-03	0.0		

ENERGY AND WORK AT THE END OF TIME CYCLE 530

FRAGMENT	KINETIC ENERGY
1	0.136119D+04

J= 530 TIME (SEC.) = 0.106000D-02 TIME AFTER INITIAL IMPACT = 0.940000D-04
WORK INPUT INTO RING (IN.-LB.) = 0.374054D+03
RING KINETIC ENERGY (IN.-LB.) = 0.161234D+03
RING ELASTIC ENERGY (IN.-LB.) = 0.918047D+02
RING PLASTIC WORK (IN.-LB.) = 0.105552D+03
ENERGY STORED IN THE ELASTIC RESTRAINTS (IN.-LB.) = 0.154641D+02

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	0.0	-0.4682D-02	0.1086D-02	0.0	0.0	0.3464D+04	0.1428D+03	0.1314D-02	0.4485D-03
2	0.9507D-03	-0.2147D-02	0.3842D-04	0.9588D-03	0.1001D+01	-0.2147D-02	0.4664D+04	0.3667D+03	0.1140D-02	0.4178D-03
3	0.1678D-02	-0.1427D-03	0.2613D-02	0.2338D-04	0.2002D+01	-0.1427D-03	0.1666D+04	0.2469D+03	-0.1147D-03	0.4512D-01
4	0.1784D-02	0.2883D-03	-0.3266D-03	0.7954D-03	0.3002D+01	0.2883D-03	0.3040D+04	0.2572D+03	0.9462D-03	0.3445D-03
5	0.2103D-02	0.1448D-02	-0.2144D-03	-0.7184D-03	0.4002D+01	0.1448D-02	0.1110D+04	0.3128D+03	-0.1051D-02	0.2811D-03
6	0.1401D-02	-0.5454D-02	-0.1240D-01	-0.3077D-03	0.5001D+01	-0.5454D-02	0.1459D+04	-0.3397D+03	-0.3904D-03	0.2482D-03
7	0.3784D-02	-0.7811D-02	0.1981D-01	0.4528D-02	0.6004D+01	-0.7811D-02	-0.1964D+03	-0.5856D+03	0.6269D-02	0.1328D-03
8	0.6433D-02	0.4465D-01	0.8388D-01	0.4081D-03	0.7006D+01	0.4465D-01	-0.1179D+04	0.1910D+01	0.5188D-02	0.1382D-03
9	0.1404D-02	0.1362D+00	0.7387D-01	-0.8062D-02	0.8001D+01	0.1362D+00	-0.2784D+04	0.3180D+03	-0.6858D-02	-0.6297D-03
10	-0.1066D-01	0.1282D+00	-0.1257D+00	-0.2033D-01	0.8989D+01	0.1282D+00	0.1450D+04	-0.2058D+03	-0.1573D-01	-0.1686D-02
11	-0.1696D-01	0.1228D-01	-0.1574D-01	0.5477D-03	0.9983D+01	0.1228D-01	-0.2133D+04	-0.7788D+03	0.1840D-02	-0.2605D-02
12	0.3837D-02	0.5058D-02	-0.1011D-01	0.3261D-04	0.1050D+02	0.1006D+01	-0.4694D+03	-0.1399D+04	0.6450D-03	-0.4775D-03
13	0.0	0.0	0.0	0.1722D-04	0.1150D+02	0.1500D+01	-0.1940D+04	-0.7236D+02	0.1256D-02	-0.1222D-02
14	-0.1765D-01	-0.7264D-02	-0.1574D-01	0.1217D-02	0.1085D+02	-0.8005D-01	-0.7721D+03	-0.8218D+02	0.1769D-02	0.5851D-04
15	-0.1517D-01	-0.1111D-01	0.7583D-02	-0.1866D-03	0.1169D+02	-0.3068D+00	-0.8021D+03	-0.2789D+02	-0.9430D-04	-0.3485D-03
16	-0.1391D-01	-0.6797D-02	0.6741D-02	-0.4779D-03	0.1248D+02	-0.6688D+00	-0.6210D+03	-0.1838D+02	-0.5208D-03	-0.2578D-03
17	-0.1323D-01	-0.4508D-02	0.4686D-02	-0.1717D-03	0.1320D+02	-0.1165D+01	-0.3458D+03	-0.1549D+02	-0.1526D-03	-0.1851D-03
18	-0.1272D-01	-0.2210D-02	0.5835D-02	-0.1125D-03	0.1382D+02	-0.1778D+01	-0.1361D+03	-0.2422D+01	-0.9402D-04	-0.9963D-04
19	-0.1265D-01	0.1673D-03	0.4685D-02	-0.9812D-04	0.1432D+02	-0.2489D+01			-0.1031D-03	-0.3929D-04

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUV =	FRWV =	FRAV =
1	0.876444D+01	-0.519873D+00	0.0	0.260796D+04	0.508411D+03	0.0

REACTIONS AT NODE	RV(LBS)	RW(LBS)	RM(IN-LBS)
1	-0.364613D+04	-0.196894D+03	0.0
13	-0.258809D+03	-0.925828D+03	0.191730D+04

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.127241D-01	9	2	3	0.105800D-02
2	0.257420D-02	11	1	1	0.101400D-02
INTERFACE	0.309256D-02	10	1	2	0.100600D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.907227D-02	9	1	0.104600D-02	2
2	0.103464D-02	11	2	0.104200D-02	1
INTERFACE	0.134700D-02	13	3	0.102200D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.881166D-02	8	1	0.102200D-02
2	0.125627D-02	13	1	0.106000D-02

9

CYCLE= 550

ELEMENT	SI STA 1	SO STA 1	SI STA 2	SO STA 2	SI STA 3	SO STA 3
1	-0.29198869D-02	0.72151655D-03	-0.14976653D-02	-0.19845969D-03	-0.45976793D-05	-0.92752927D-03
	-0.10991852D-02	0.0	-0.84806249D-03	0.0	-0.46606347D-03	0.0
2	0.68256662D-03	-0.13997157D-02	0.11492657D-02	-0.15408522D-02	0.15346708D-02	-0.17250746D-02
	-0.35857454D-03	0.0	-0.19579324D-03	0.0	-0.95201873D-04	0.0
3	0.10873885D-02	-0.14649597D-02	-0.89025304D-03	-0.16167086D-03	-0.28631511D-02	0.94780290D-03
	-0.18878557D-03	0.0	-0.52596195D-03	0.0	-0.95767409D-03	0.0
4	-0.32935599D-02	0.12527335D-02	-0.28438423D-02	0.10025884D-02	-0.25559976D-02	0.62773369D-03
	-0.10204132D-02	0.0	-0.92062695D-03	0.0	-0.96413194D-03	0.0
5	-0.20790167D-02	0.52740580D-03	0.23878667D-03	-0.11990094D-02	0.27668201D-02	-0.24236881D-02
	-0.77580547D-03	0.0	-0.48011138D-03	0.0	0.17156601D-03	0.0
6	0.44766422D-02	-0.37069807D-02	0.63371620D-02	-0.45848995D-02	0.79567068D-02	-0.54543732D-02
	0.38483075D-03	0.0	0.87613125D-03	0.0	0.12511668D-02	0.0
7	0.74859338D-02	-0.51852548D-02	0.49131482D-02	-0.35108433D-02	0.28905376D-02	-0.16230699D-02
	0.11502895D-02	0.0	0.70115248D-03	0.0	0.63373387D-03	0.0
8	0.11818402D-02	-0.10073454D-02	-0.44619397D-02	0.24472804D-02	-0.10024222D-01	0.50548266D-02
	0.87247408D-04	0.0	-0.10073296D-02	0.0	-0.24846978D-02	0.0
9	-0.12314783D-01	0.67620151D-02	-0.16503925D-01	0.84546619D-02	-0.18841125D-01	0.11170487D-01
	-0.27763838D-02	0.0	-0.40246315D-02	0.0	-0.38353190D-02	0.0
10	-0.67998272D-02	0.23342492D-02	0.86783808D-02	-0.40420202D-02	0.98863261D-02	-0.21695287D-01
	-0.22327890D-02	0.0	0.23181803D-02	0.0	-0.59044806D-02	0.0
11	0.11219134D-02	-0.43984617D-03	0.83374125D-03	-0.12837102D-02	0.12308539D-02	-0.14422902D-02
12	0.18086386D-02	-0.17597630D-02	0.28851906D-02	-0.29819872D-02	0.40611546D-02	-0.41047995D-02
13	0.70700446D-03	-0.13070912D-03	0.27734103D-03	-0.28066107D-04	0.13440257D-04	0.24154065D-03
	0.28814767D-03	0.0	0.12463746D-03	0.0	0.12749045D-03	0.0
14	0.47642360D-03	-0.46601087D-04	0.16694560D-02	-0.69456511D-03	0.28119343D-02	-0.14046997D-02
	0.21491125D-03	0.0	0.48744544D-03	0.0	0.70361733D-03	0.0
15	0.26531899D-02	-0.12390595D-02	0.12162116D-02	-0.37738380D-03	-0.22281741D-03	0.47622387D-03
	0.70706520D-03	0.0	0.41941390D-03	0.0	0.12670323D-03	0.0
16	-0.67979939D-03	0.75524059D-03	-0.35779647D-03	0.54021538D-03	-0.14602420D-04	0.35034030D-03
	0.37720597D-04	0.0	0.91209457D-04	0.0	0.16786894D-03	0.0
17	0.17572195D-03	0.13413387D-03	0.18443315D-03	0.13430561D-03	0.16565597D-03	0.10618791D-03
	0.15492791D-03	0.0	0.15936938D-03	0.0	0.13592194D-03	0.0
18	0.14161304D-03	0.27133785D-04	0.57505351D-04	0.34020312D-04	0.42351551D-05	0.72305181D-04
	0.84373411D-04	0.0	0.45762831D-04	0.0	0.38270168D-04	0.0

CYCLE= 550

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.16811592D-01	0.85680215D-02	-0.16955324D-01	0.85316272D-02
	-0.44721704D-02	0.0		
2	0.83374125D-03	-0.12837102D-02	0.83339397D-03	-0.12845352D-02
3	0.80109403D-03	-0.12268431D-03	0.80077341D-03	-0.12269184D-03
	0.33920486D-03	0.0		

ENERGY AND WORK AT THE END OF TIME CYCLE 550

FRAGMENT	KINETIC ENERGY
1	0.136119D+04

J= 550 TIME (SEC.) = 0.1100000D-02 TIME AFTER INITIAL IMPACT = 0.1340000D-03
WORK INPUT INTO RING (IN.-LB.) = 0.374054D+03
RING KINETIC ENERGY (IN.-LB.) = 0.121609D+03
RING ELASTIC ENERGY (IN.-LB.) = 0.116116D+03
RING PLASTIC WORK (IN.-LB.) = 0.116917D+03
ENERGY STORED IN THE ELASTIC RESTRAINTS (IN.-LB.) = 0.194124D+02

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	0.0	0.3634D-03	-0.2233D-02	0.0	0.0	-0.5853D+04	-0.4122D+03	-0.2774D-02	-0.6010D-03
2	-0.1153D-02	-0.3544D-02	-0.4117D-02	0.4701D-04	0.9988D+00	-0.3544D-02	-0.4136D+04	-0.8083D+03	0.2708D-03	-0.5905D-03
3	-0.7007D-03	-0.3210D-02	0.5847D-02	0.7613D-03	0.1999D+01	-0.3210D-02	-0.3198D+04	-0.2060D+03	0.1214D-02	-0.5268D-03
4	-0.1449D-02	0.3938D-02	0.2932D-02	-0.2270D-02	0.2999D+01	0.3938D-02	-0.3042D+04	0.1476D+03	-0.2852D-02	-0.4952D-03
5	-0.3404D-02	-0.2008D-02	-0.1379D-01	-0.1852D-02	0.3997D+01	-0.2008D-02	-0.4027D+04	-0.4415D+03	-0.2183D-02	-0.4739D-03
6	-0.3555D-02	-0.1642D-01	-0.6945D-02	0.1975D-02	0.4996D+01	-0.1642D-01	-0.2591D+04	-0.9661D+03	0.2849D-02	-0.5430D-03
7	-0.3099D-03	0.1909D-02	0.5054D-01	0.3642D-02	0.6000D+01	0.1909D-02	-0.2235D+04	-0.5715D+03	0.6679D-02	-0.3354D-03
8	-0.6795D-03	0.8190D-01	0.1001D+00	-0.3530D-02	0.6999D+01	0.8190D-01	-0.7264D+03	0.2710D+03	0.2013D-02	-0.9936D-04
9	-0.7533D-02	0.1719D+00	0.5403D-01	-0.8551D-02	0.7992D+01	0.1719D+00	-0.1295D+04	0.3133D+03	-0.9211D-02	-0.5878D-03
10	-0.1953D-01	0.1414D+00	-0.1380D+00	-0.2033D-01	0.8980D+01	0.1414D+00	0.1847D+04	-0.1959D+03	-0.1357D-01	-0.1723D-02
11	-0.2596D-01	0.1970D-01	-0.2232D-01	0.3849D-03	0.9974D+01	0.1970D-01	-0.2611D+04	-0.8192D+03	0.1924D-02	-0.3062D-02
12	0.6498D-02	0.8518D-02	-0.1640D-01	-0.7610D-04	0.1050D+02	0.1010D+01	-0.5617D+03	-0.2270D+04	0.7752D-03	-0.6584D-03
13	0.0	0.0	0.0	0.1224D-04	0.1150D+02	0.1500D+01	0.2558D+03	0.3392D+01	0.2221D-02	-0.2196D-02
14	-0.2740D-01	-0.2449D-02	-0.1966D-01	-0.1476D-03	0.1084D+02	-0.7362D-01	0.5835D+03	-0.2568D+02	0.2100D-04	0.1195D-03
15	-0.2449D-01	-0.1821D-01	0.1003D-02	0.2031D-02	0.1168D+02	-0.3103D+00	0.6591D+03	-0.7428D+01	0.2616D-02	0.2858D-03
16	-0.2108D-01	-0.1142D-01	0.1492D-01	-0.4981D-03	0.1248D+02	-0.6692D+00	0.5870D+03	0.3982D+02	-0.5715D-03	0.1678D-03
17	-0.1979D-01	-0.6262D-02	0.7079D-02	0.1329D-03	0.1319D+02	-0.1162D+01	0.4485D+03	0.1567D+02	0.1472D-03	0.1900D-03
18	-0.1883D-01	-0.3269D-02	0.7518D-02	0.1115D-03	0.1382D+02	-0.1774D+01	0.1255D+03	0.4197D+01	0.1524D-03	0.1016D-03
19	-0.1854D-01	0.2803D-03	0.[illegible]722D-02	-0.1462D-04	0.1432D+02	-0.2484D+01			0.3343D-05	0.5075D-04

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUV =	FRWV =	FRAV =
1	0.886876D+01	-0.499536D+00	0.0	0.260796D+04	0.508411D+03	0.0

REACTIONS AT NODE	RV(LBS)	RW(LBS)	RM(IN-LBS)
1	0.564348D+04	0.834679D+03	0.0
13	-0.369374D+03	-0.205052D+04	0.341751D+04

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.127241D-01	9	2	3	0.1058000D-02
2	0.406115D-02	12	1	3	0.1100000D-02
INTERFACE	0.309256D-02	10	1	2	0.1006000D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.907227D-02	9	1	0.1046000D-02	2
2	0.103464D-02	11	2	0.1042000D-02	1
INTERFACE	0.134700D-02	13	3	0.1022000D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.881166D-02	8	1	0.1022000D-02
2	0.222096D-02	13	1	0.1100000D-02

ORIGINAL PAGE IS
OF POOR QUALITY

CYCLE= 570

ELEMENT	SI (STA 1)	SO (STA 1)	SI (STA 2)	SO (STA 2)	SI (STA 3)	SO (STA 3)
1	-0.17510452D-02	0.37921932D-03	-0.98747467D-03	-0.11982244D-03	-0.21409759D-03	-0.54456884D-03
	-0.68591294D-03	0.0	-0.55364855D-03	0.0	-0.17933321D-03	0.0
2	0.55162423D-04	-0.78068910D-03	-0.44813677D-04	-0.66638673D-03	-0.21772011D-03	-0.63597194D-03
	-0.36276334D-03	0.0	-0.35560020D-03	0.0	-0.42684603D-03	0.0
3	-0.57275632D-03	-0.41651899D-03	-0.15530422D-02	0.16361563D-03	-0.25526390D-02	0.62745273D-03
	-0.49463766D-03	0.0	-0.69471330D-03	0.0	-0.96259312D-03	0.0
4	-0.28596655D-02	0.93464746D-03	-0.23479183D-02	0.41044353D-03	-0.16670538D-02	0.11680799D-03
	-0.96250902D-03	0.0	-0.96873740D-03	0.0	-0.77512293D-03	0.0
5	-0.31952227D-03	-0.86235781D-03	0.28470046D-02	-0.27347155D-02	0.57932278D-02	-0.44532993D-02
	-0.59044004D-03	0.0	0.56144528D-04	0.0	0.66996426D-03	0.0
6	0.71955097D-02	-0.59689274D-02	0.72877427D-02	-0.55471204D-02	0.70046249D-02	-0.54854907D-02
	0.61329113D-03	0.0	0.87031113D-03	0.0	0.75956711D-03	0.0
7	0.54195189D-02	-0.44862724D-02	0.18555596D-02	-0.24359889D-02	-0.96835814D-03	-0.11794539D-03
	0.46652324D-03	0.0	-0.29021465D-03	0.0	-0.54315177D-03	0.0
8	-0.26583062D-02	0.54115573D-03	-0.76299116D-02	0.31821350D-02	-0.12232636D-01	0.53895448D-02
	-0.10585752D-02	0.0	-0.22238883D-02	0.0	-0.34215457D-02	0.0
9	-0.13273446D-01	0.57722268D-02	-0.15257011D-01	0.71448955D-02	-0.16372680D-01	0.86626120D-02
	-0.36506106D-02	0.0	-0.40560575D-02	0.0	-0.38550338D-02	0.0
10	-0.61004992D-02	0.15422833D-02	0.79649661D-02	-0.48004836D-02	0.92540992D-02	-0.21116184D-01
	-0.22791079D-02	0.0	0.15822412D-02	0.0	-0.59310422D-02	0.0
11	0.94294064D-03	-0.35426121D-03	0.12285112D-02	-0.14770638D-02	0.20328237D-02	-0.20820249D-02
12	0.26193331D-02	-0.24345291D-02	0.33926147D-02	-0.32992220D-02	0.42236724D-02	-0.41151390D-02
13	0.98053026D-03	-0.21000892D-02	-0.27829539D-03	-0.12124708D-02	-0.15227740D-02	-0.31711234D-03
	-0.55972945D-03	0.0	-0.74538309D-03	0.0	-0.91994315D-03	0.0
14	-0.13699068D-02	-0.55973813D-03	-0.36062729D-04	-0.11825940D-02	0.12126900D-02	-0.18955264D-02
	-0.96482245D-03	0.0	-0.60932834D-03	0.0	-0.34141820D-03	0.0
15	0.14980905D-02	-0.20191710D-02	0.11068223D-02	-0.17092773D-02	0.75342210D-03	-0.13752243D-02
	-0.26054027D-03	0.0	-0.30122748D-03	0.0	-0.31090108D-03	0.0
16	0.32536733D-03	-0.11175063D-02	-0.54720569D-03	-0.41837786D-03	-0.15081198D-02	0.19337697D-03
	-0.39636946D-03	0.0	-0.48279177D-03	0.0	-0.65737142D-03	0.0
17	-0.16618568D-02	0.46037825D-03	-0.82335975D-03	0.17383087D-04	0.41816092D-04	-0.39544650D-03
	-0.60073927D-03	0.0	-0.40298833D-03	0.0	-0.17681520D-03	0.0
18	0.29852858D-03	-0.44476142D-03	0.84920627D-04	-0.17824649D-03	-0.23681940D-03	-0.22913173D-04
	-0.73116420D-04	0.0	-0.46662930D-04	0.0	-0.12986629D-03	0.0

CYCLE= 570

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.15406895D-01	0.72169586D-02	-0.15527446D-01	0.71911026D-02
	-0.44073124D-02	0.0		
2	0.12285112D-02	-0.14770638D-02	0.12277575D-02	-0.14781563D-02
3	0.12271620D-02	-0.22017032D-02	0.12264100D-02	-0.22041323D-02
	-0.48727057D-03	0.0		

ENERGY AND WORK AT THE END OF TIME CYCLE 570

FRAGMENT	KINETIC ENERGY
1	0.1361190D+04

J= 570 TIME (SEC.) = 0.1140000D-02 TIME AFTER INITIAL IMPACT = 0.1740000D-03
WORK INPUT INTO RING (IN.-LB.) = 0.3740540D+03
RING KINETIC ENERGY (IN.-LB.) = 0.9779680D+02
RING ELASTIC ENERGY (IN.-LB.) = 0.1277480D+03
RING PLASTIC WORK (IN.-LB.) = 0.1264000D+03
ENERGY STORED IN THE ELASTIC RESTRAINTS (IN.-LB.) = 0.2211010D+02

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	0.0	0.2260D-02	-0.1346D-02	0.0	0.0	-0.3801D+04	-0.2636D+03	-0.1657D-02	-0.4016D-03
2	-0.7642D-03	-0.1317D-03	-0.7320D-03	-0.1547D-03	0.9992D+00	-0.1317D-03	-0.3408D+04	-0.4329D+03	-0.5644D-04	-0.4483D-03
3	-0.9858D-03	0.4395D-03	0.1570D-02	-0.3734D-03	0.1999D+01	0.4395D-03	-0.3552D+04	-0.1152D+03	-0.3298D-03	-0.4991D-03
4	-0.2125D-02	-0.7660D-04	-0.5296D-02	-0.1963D-02	0.2998D+01	-0.7660D-04	-0.4258D+04	-0.7172D+02	-0.2428D-02	-0.5038D-03
5	-0.3813D-02	-0.1222D-01	-0.1729D-01	-0.1212D-02	0.3996D+01	-0.1222D-01	-0.3834D+04	-0.7927D+03	-0.1218D-02	-0.5924D-03
6	-0.2473D-02	-0.2140D-01	0.9290D-02	0.3729D-02	0.4998D+01	-0.2140D-01	-0.3774D+04	-0.1109D+04	0.5329D-02	-0.8692D-03
7	0.3901D-03	0.2145D-01	0.7684D-01	0.8073D-03	0.6000D+01	0.2145D-01	-0.4661D+04	-0.4856D+03	0.5261D-02	-0.7429D-03
8	-0.3305D-02	0.1175D+00	0.1021D+00	-0.6350D-02	0.6997D+01	0.1175D+00	-0.3621D+04	0.2552D+03	-0.1312D-02	-0.5389D-03
9	-0.1143D-01	0.1947D+00	0.3001D-01	-0.8832D-02	0.7989D+01	0.1947D+00	-0.2600D+04	0.1637D+03	-0.1070D-01	-0.1272D-02
10	-0.2341D-01	0.1455D+00	-0.1423D+00	-0.2005D-01	0.8977D+01	0.1455D+00	-0.6696D+03	-0.2928D+03	-0.1221D-01	-0.2252D-02
11	-0.3034D-01	0.2227D-01	-0.2627D-01	0.1663D-03	0.9970D+01	0.2227D-01	-0.1442D+04	-0.1047D+04	0.1891D-02	-0.3517D-02
12	0.6945D-02	0.9245D-02	-0.1870D-01	-0.7099D-04	0.1049D+02	0.1010D+01	0.5419D+03	-0.2589D+04	0.1240D-02	-0.1032D-02
13	0.0	0.0	0.0	0.7162D-04	0.1150D+02	0.1500D+01	-0.2514D+04	-0.1122D+03	0.2276D-02	-0.2133D-02
14	-0.3285D-01	0.8771D-03	-0.1810D-01	-0.1664D-02	0.1084D+02	-0.6939D-01	-0.2192D+04	-0.1045D+03	-0.1699D-02	-0.8979D-03
15	-0.3153D-01	-0.1946D-01	-0.8081D-02	0.6892D-03	0.1167D+02	-0.3090D+00	-0.1885D+04	-0.1265D+03	0.1185D-02	-0.6662D-03
16	-0.2746D-01	-0.1977D-01	0.1653D-01	0.6052D-05	0.1247D+02	-0.6733D+00	-0.1367D+04	-0.4824D+02	0.3821D-03	-0.5757D-03
17	-0.2569D-01	-0.7856D-02	0.1540D-01	-0.1431D-02	0.1319D+02	-0.1159D+01	-0.8794D+03	-0.1585D+02	-0.1602D-02	-0.4386D-03
18	-0.2530D-01	-0.4177D-02	0.8056D-02	0.1039D-03	0.1381D+02	-0.1769D+01	-0.2304D+03	-0.1384D+02	0.2421D-03	-0.1809D-03
19	-0.2498D-01	0.2715D-03	0.1036D-01	-0.3325D-03	0.1432D+02	-0.2478D+01			-0.3229D-03	-0.1468D-03

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUV =	FRWV =	FRAV =
1	0.8973070D+01	-0.4792000D+00	0.0	0.2607960D+04	0.5084110D+03	0.0

REACTIONS AT NODE	RV(LBS)	RW(LBS)	RM(IN-LBS)
1	0.3727770D+04	0.4941850D+03	0.0
13	0.6475120D+03	-0.1465180D+04	0.3402030D+04

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.1272410D-01	9	2	3	0.1058000D-02
2	0.4223670D-02	12	1	3	0.1140000D-02
INTERFACE	0.3092560D-02	10	1	2	0.1006000D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.9072270D-02	9	1	0.1046000D-02	2
2	0.1228510D-02	11	2	0.1140000D-02	1
INTERFACE	0.1347000D-02	13	3	0.1022000D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.8811660D-02	8	1	0.1022000D-02
2	0.2276140D-02	13	1	0.1140000D-02

CYCLE= 590

ELEMENT	SI STA 1	SO	SI STA 2	SO	SI STA 3	SO
1	-0.46411948D-04	0.15425307D-04	-0.59671976D-03	0.39369569D-03	-0.11623871D-02	0.68795616D-03
	-0.54933205D-05	0.0	-0.10151204D-03	0.0	-0.23721546D-03	0.0
2	-0.16453460D-02	0.10380165D-02	-0.25306419D-02	0.15197996D-02	-0.33165050D-02	0.20182821D-02
	-0.30366474D-03	0.0	-0.50542117D-03	0.0	-0.64911148D-03	0.0
3	-0.31265010D-02	0.19201119D-02	-0.18436784D-02	0.11612890D-02	-0.66979615D-03	0.41064366D-03
	-0.60319455D-03	0.0	-0.34119473D-03	0.0	-0.12957625D-03	0.0
4	0.21440206D-01	-0.10430314D-03	0.21407755D-02	-0.13126952D-02	0.19577261D-02	-0.24186647D-02
	0.55049462D-04	0.0	0.41404017D-03	0.0	0.76953070D-03	0.0
5	0.46955851D-02	-0.29024280D-02	0.53450025D-02	-0.33498063D-02	0.60536038D-02	-0.36371494D-02
	0.89657855D-03	0.0	0.99759810D-03	0.0	0.12087272D-02	0.0
6	0.64061718D-02	-0.42137401D-02	0.61221422D-02	-0.38831882D-02	0.58817234D-02	-0.35261393D-02
	0.10957159D-02	0.0	0.11194770D-02	0.0	0.11777921D-02	0.0
7	0.47760938D-02	-0.30721137D-02	0.11839211D-02	-0.67882800D-03	-0.20930657D-02	0.15153623D-02
	0.85199002D-03	0.0	0.25254652D-03	0.0	-0.28885169D-03	0.0
8	-0.40805429D-02	0.26385513D-02	-0.83215237D-02	0.44687363D-02	-0.11907802D-01	0.62925208D-02
	-0.72099580D-03	0.0	-0.19263937D-02	0.0	-0.28076408D-02	0.0
9	-0.12235943D-01	0.62041077D-02	-0.13845309D-01	0.75247941D-02	-0.15128288D-01	0.86991239D-02
	-0.30159177D-02	0.0	-0.31602573D-02	0.0	-0.32145821D-02	0.0
10	-0.48560736D-02	0.20871750D-02	0.94764165D-02	-0.46186213D-02	0.10208259D-01	-0.22026451D-01
	-0.13844493D-02	0.0	0.24288976D-02	0.0	-0.59090959D-02	0.0
11	0.12210450D-02	-0.23024403D-03	0.78367674D-03	-0.13061040D-02	0.12497906D-02	-0.14784829D-02
12	0.18319662D-02	-0.17515230D-02	0.30318902D-02	-0.31747923D-02	0.44086878D-02	-0.44211901D-02
13	0.18426137D-02	-0.18767723D-02	0.12056370D-02	-0.55282051D-03	-0.26806726D-03	-0.92733967D-04
	-0.17077263D-04	0.0	0.32640823D-03	0.0	-0.18040062D-03	0.0
14	-0.10785076D-02	0.56571591D-03	-0.67711747D-03	0.21372769D-03	-0.25514243D-03	-0.11264385D-03
	-0.25639583D-03	0.0	-0.23169489D-03	0.0	-0.18389314D-03	0.0
15	0.31983339D-03	-0.39755948D-03	0.14807476D-02	-0.12030637D-02	0.27212063D-02	-0.19404351D-02
	-0.38863042D-04	0.0	0.13884196D-03	0.0	0.39038559D-03	0.0
16	0.24935135D-02	-0.18157405D-02	0.68857261D-03	-0.77564357D-03	-0.10007060D-02	0.37921375D-03
	0.33888653D-03	0.0	-0.43535478D-04	0.0	-0.31074613D-03	0.0
17	-0.14407966D-02	0.53006939D-03	-0.11089650D-02	0.41872369D-03	-0.76436652D-03	0.32655680D-03
	-0.45536361D-03	0.0	-0.34512064D-03	0.0	-0.21890486D-03	0.0
18	-0.42853892D-03	0.42042916D-04	-0.14706560D-03	0.46665880D-04	-0.89660796D-05	-0.94198514D-04
	-0.19324800D-03	0.0	-0.50199860D-04	0.0	-0.51582297D-04	0.0

CYCLE= 590

STRAIN AT ADDITIONAL POINTS

	SI	SO	EI	EO
1	-0.13986332D-01	0.75910048D-02	-0.14085533D-01	0.75624097D-02
	-0.34955593D-02	0.0		
2	0.78367674D-03	-0.13061040D-02	0.78336991D-03	-0.13069580D-02
3	0.19082549D-02	-0.21311487D-02	0.19064377D-02	-0.21334245D-02
	-0.11144690D-03	0.0		

ENERGY AND WORK AT THE END OF TIME CYCLE 590

FRAGMENT	KINETIC ENERGY
1	0.136119D+04

J= 590 TIME (SEC.) = 0.118000D-02 TIME AFTER INITIAL IMPACT = 0.214000D-03
WORK INPUT INTO RING (IN.-LB.) = 0.374054D+03
RING KINETIC ENERGY (IN.-LB.) = 0.103389D+03
RING ELASTIC ENERGY (IN.-LB.) = 0.115838D+03
RING PLASTIC WORK (IN.-LB.) = 0.131968D+03
ENERGY STORED IN THE ELASTIC RESTRAINTS (IN.-LB.) = 0.228596D+02

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	0.0	0.8729D-02	0.2433D-04	0.0	0.0	0.1626D+03	0.1845D+03	0.8639D-04	-0.9458D-05
2	-0.3870D-03	0.7697D-02	0.5313D-02	-0.8206D-03	0.9996D+00	0.7697D-02	-0.9407D+02	0.5823D+03	-0.1079D-02	0.1165D-04
3	-0.1894D-02	0.6658D-02	-0.9688D-02	-0.2147D-02	0.1998D+01	0.6658D-02	0.1824D+03	0.3933D+03	-0.2807D-02	0.3169D-04
4	-0.3166D-02	-0.1067D-01	-0.2171D-01	-0.4535D-03	0.2997D+01	-0.1067D-01	-0.4534D+02	-0.3700D+03	-0.2912D-03	0.2692D-05
5	-0.2063D-02	-0.2781D-01	-0.6693D-02	0.2660D-02	0.3998D+01	-0.2781D-01	-0.3797D+03	-0.7981D+03	0.3589D-02	-0.2257D-04
6	0.9762D-03	-0.1520D-01	0.3471D-01	0.3191D-02	0.5001D+01	-0.1520D-01	-0.4725D+03	-0.6712D+03	0.5096D-02	-0.9411D-04
7	0.2614D-02	0.4606D-01	0.8737D-01	-0.3096D-03	0.6003D+01	0.4606D-01	-0.4895D+03	-0.8118D+02	0.4690D-02	-0.4095D-04
8	-0.1636D-02	0.1461D+00	0.9833D-01	-0.6569D-02	0.6998D+01	0.1461D+00	-0.6310D+03	0.4638D+03	-0.2334D-02	0.1491D-03
9	-0.9068D-02	0.2109D+00	0.1306D-01	-0.7758D-02	0.7991D+01	0.2109D+00	0.3296D+03	0.2703D+03	-0.9965D-02	-0.6776D-03
10	-0.2368D-01	0.1484D+00	-0.1513D+00	-0.2063D-01	0.8979D+01	0.1484D+00	0.1908D+04	-0.2055D+03	-0.1135D-01	-0.1834D-02
11	-0.2732D-01	0.2085D-01	-0.2319D-01	0.6158D-03	0.9973D+01	0.2085D-01	-0.3032D+04	-0.9084D+03	0.2388D-02	-0.3465D-02
12	0.6355D-02	0.9111D-02	-0.1735D-01	-0.5163D-04	0.1049D+02	0.1010D+01	-0.8292D+03	-0.2401D+04	0.8156D-03	-0.6179D-03
13	0.0	0.0	0.0	0.5527D-04	0.1150D+02	0.1500D+01	0.3282D+03	-0.2304D+02	0.2454D-02	-0.2343D-02
14	-0.2904D-01	0.5587D-02	-0.7779D-02	-0.7767D-03	0.1084D+02	-0.6542D-01	-0.3604D+03	0.4453D+01	-0.9084D-03	-0.2591D-03
15	-0.2914D-01	-0.1096D-01	-0.1557D-01	-0.2456D-03	0.1168D+02	-0.3019D+00	-0.5506D+03	-0.7426D+02	-0.1106D-03	-0.1660D-03
16	-0.2525D-01	-0.2234D-01	0.7883D-02	0.1852D-02	0.1247D+02	-0.6766D+00	-0.6494D+03	-0.5349D+02	0.2533D-02	-0.6114D-04
17	-0.2218D-01	-0.9293D-02	0.2066D-01	-0.1235D-02	0.1319D+02	-0.1163D+01	-0.4652D+03	0.1332D+02	-0.1290D-02	-0.2131D-03
18	-0.2211D-01	-0.1662D-02	0.7315D-02	-0.4354D-03	0.1381D+02	-0.1770D+01	-0.7782D+02	0.9887D+00	-0.5033D-03	-0.1244D-03
19	-0.2209D-01	-0.3283D-03	0.5630D-02	-0.4413D-04	0.1432D+02	-0.2481D+01			-0.7435D-05	-0.9084D-04

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUV =	FRWV =	FRAV =
1	0.907739D+01	-0.458863D+00	0.0	0.260796D+04	0.508411D+03	0.0

REACTIONS AT NODE	RV(LBS)	RW(LBS)	RM(IN-LBS)
1	-0.986719D+02	-0.344694D+03	0.0
13	-0.539901D+03	-0.224871D+04	0.363887D+04

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.127241D-01	9	2	3	0.105800D-02
2	0.440869D-02	12	1	3	0.118000D-02
INTERFACE	0.309256D-02	10	1	2	0.100600D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.907227D-02	9	1	0.104600D-02	2
2	0.129943D-02	11	2	0.115000D-02	1
INTERFACE	0.134700D-02	13	3	0.102200D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.881166D-02	8	1	0.102200D-02
2	0.245358D-02	13	1	0.118000D-02

IMPACT NO. 2 TIME 0.121800D-02 DURING CYCLE 610 ELEM 10 FRAG 1 DISTANCE 0.271972D+00
FRAG 1 TE= 0.1239D+04 RE= 0.0 TOE= 0.1239D+04 FRAG

IMPACT NO. 1 TIME 0.129600D-02 DURING CYCLE 649 ELEM 10 FRAG 1 DISTANCE 0.492054D+00
FRAG 1 TI= 0.1219D+04 RE= 0.0 TOE= 0.1219D+04 FRAG

CYCLE= 770

ELEMENT	SI (STA 1)	SO (STA 1)	SI (STA 2)	SO (STA 2)	SI (STA 3)	SO (STA 3)
1	-0.46197173D-03	0.28005973D-03	-0.45569344D-03	0.23514265D-03	-0.19627964D-03	0.44506472D-03
	-0.90956000D-04	0.0	-0.11027540D-03	0.0	0.12439254D-03	0.0
2	0.89721309D-03	-0.36493890D-03	0.31327935D-02	-0.12998239D-02	0.49562585D-02	-0.24628910D-02
	0.26613709D-03	0.0	0.91648481D-03	0.0	0.12466838D-02	0.0
3	0.54532197D-02	-0.28920737D-02	0.54056084D-02	-0.29476083D-02	0.52597097D-02	-0.30853977D-02
	0.12805730D-02	0.0	0.12290001D-02	0.0	0.10871560D-02	0.0
4	0.54554887D-02	-0.32016506D-02	0.63618311D-02	-0.36680970D-02	0.72829987D-02	-0.40082541D-02
	0.11269190D-02	0.0	0.13468671D-02	0.0	0.16373723D-02	0.0
5	0.67157447D-02	-0.37718134D-02	0.35956102D-02	-0.17600065D-02	0.50270087D-03	-0.72041035D-04
	0.14719656D-02	0.0	0.91780187D-03	0.0	0.21532992D-03	0.0
6	-0.11710932D-02	0.75627521D-03	-0.35045750D-02	0.21127534D-02	-0.53556039D-02	0.36446622D-02
	-0.20740899D-03	0.0	-0.69591081D-03	0.0	-0.85547088D-03	0.0
7	-0.59475807D-02	0.37255048D-02	-0.78805921D-02	0.50654446D-02	-0.95906874D-02	0.62916247D-02
	-0.11110380D-02	0.0	-0.14075737D-02	0.0	-0.16495313D-02	0.0
8	-0.88116097D-02	0.55310191D-02	-0.51592355D-02	0.35202827D-02	-0.17871754D-02	0.17337911D-02
	-0.16402953D-02	0.0	-0.81747642D-03	0.0	-0.26692146D-04	0.0
9	-0.13225767D-02	0.57324737D-03	-0.47615426D-02	0.35150089D-02	-0.78177177D-02	0.60664737D-02
	-0.37466465D-03	0.0	-0.62326689D-03	0.0	-0.87562200D-03	0.0
10	-0.65693559D-03	0.15735201D-02	0.92950038D-02	-0.33632785D-02	0.79664984D-02	-0.17504234D-01
	0.45834212D-03	0.0	0.29658626D-02	0.0	-0.47688677D-02	0.0
11	-0.63475093D-03	0.26397642D-03	0.32828320D-03	0.12683762D-03	0.89919747D-03	-0.40262010D-03
12	0.79710561D-03	-0.34579451D-03	0.26700445D-02	-0.19233042D-02	0.45659070D-02	-0.34779912D-02
13	0.15244712D-03	-0.49586736D-03	0.69635461D-03	0.46149630D-03	0.20491982D-03	0.36126267D-03
	-0.17171012D-03	0.0	0.57892545D-03	0.0	0.28309124D-03	0.0
14	0.68900861D-04	0.51077605D-03	0.92457893D-03	0.12931563D-03	0.14811440D-02	-0.56026104D-03
	0.28983846D-03	0.0	0.52694728D-03	0.0	0.46044150D-03	0.0
15	0.12160668D-02	0.10700397D-03	0.12569392D-02	-0.35232168D-03	0.17778288D-02	-0.33009070D-03
	0.66153539D-03	0.0	0.45230877D-03	0.0	0.72386905D-03	0.0
16	0.16557471D-02	-0.63366168D-03	-0.21970393D-03	0.68729993D-03	-0.22421432D-02	0.18649936D-02
	0.51104271D-03	0.0	0.23379800D-03	0.0	-0.18857476D-03	0.0
17	-0.20680442D-02	0.16128619D-02	0.14663770D-03	0.37855155D-03	0.21442174D-02	-0.10748022D-02
	-0.22759116D-03	0.0	0.26259463D-03	0.0	0.53470761D-03	0.0
18	0.23960959D-02	-0.11060100D-02	0.16211067D-02	-0.86395217D-03	0.10495250D-02	-0.42637608D-03
	0.64504297D-03	0.0	0.37857729D-03	0.0	0.31157446D-03	0.0

CYCLE= 770

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.50309014D-02	0.37076383D-02	-0.50436204D-02	0.37077904D-02
	-0.78227550D-03	0.0		
2	0.32828320D-03	0.12683762D-03	0.32822933D-03	0.12682958D-03
3	-0.26762283D-04	-0.74360704D-03	-0.26262628D-04	-0.74388372D-03
	-0.38493466D-03	0.0		

ENERGY AND WORK AT THE END OF TIME CYCLE 770

ORIGINAL PAGE IS
OF POOR QUALITY

FRAGMENT	KINETIC ENERGY
1	0.121866D+04

J= 770 TIME (SEC.) = 0.154000D-02 TIME AFTER INITIAL IMPACT = 0.574000D-03
WORK INPUT INTO RING (IN.-LB.) = 0.516582D+03
RING KINETIC ENERGY (IN.-LB.) = 0.831107D+02
RING ELASTIC ENERGY (IN.-LB.) = 0.119100D+03
RING PLASTIC WORK (IN.-LB.) = 0.297698D+03
ENERGY STORED IN THE ELASTIC RESTRAINTS (IN.-LB.) = 0.166737D+02

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	0.0	-0.1782D-01	-0.3857D-03	0.0	0.0	-0.3210D+03	0.9876D+02	-0.3216D-03	0.5704D-04
2	-0.3439D-03	-0.1903D-01	-0.2020D-01	-0.1204D-03	0.9996D+00	-0.1903D-01	0.6599D+03	-0.1957D+03	0.6343D-04	0.1440D-03
3	0.1409D-02	-0.3357D-01	-0.3781D-02	0.3349D-02	0.2001D+01	-0.3357D-01	0.3490D+03	-0.8537D+03	0.4398D-02	0.2501D-03
4	0.4568D-02	-0.2087D-01	0.2963D-01	0.2674D-02	0.3005D+01	-0.2087D-01	0.2388D+03	-0.9568D+03	0.4152D-02	0.8065D-05
5	0.7107D-02	0.2902D-01	0.7324D-01	0.1987D-02	0.4007D+01	0.2902D-01	0.2734D+03	-0.3012D+03	0.6146D-02	0.2251D-03
6	0.5185D-02	0.1199D+00	0.9874D-01	-0.5120D-02	0.5005D+01	0.1199D+00	0.1735D+02	0.4936D+03	-0.3285D-03	0.5809D-04
7	-0.7501D-03	0.2081D+00	0.6918D-01	-0.5685D-02	0.5999D+01	0.2081D+00	0.7437D+03	0.7260D+03	-0.4437D-02	0.2088D-03
8	-0.6255D-02	0.2439D+00	-0.6975D-02	-0.5803D-02	0.6994D+01	0.2439D+00	0.1786D+04	0.4003D+03	-0.7809D-02	0.3814D-03
9	-0.1036D-01	0.2009D+00	-0.6481D-01	-0.2536D-02	0.7970D+01	0.2009D+00	0.3256D+04	-0.5614D+02	-0.5584D-03	-0.5560D-04
10	-0.1690D-01	0.1150D+00	-0.1285D+00	-0.1287D-01	0.8983D+01	0.1150D+00	0.9820D+03	-0.3379D+02	-0.5926D-02	-0.3456D-03
11	-0.1938D-01	0.1519D-01	-0.1340D-01	-0.4691D-03	0.9981D+01	0.1519D-01	0.2641D+04	-0.7793D+02	0.4932D-03	-0.3149D-02
12	0.5398D-02	0.7823D-02	-0.1284D-01	0.9850D-04	0.1050D+02	0.1008D+01	0.4333D+04	-0.1777D+04	0.4010D-03	-0.3919D-04
13	0.0	0.0	0.0	0.6077D-03	0.1150D+02	0.1500D+01	0.1610D+04	0.5517D+02	0.2870D-02	-0.1654D-02
14	-0.2057D-01	0.1550D-02	-0.1130D-01	-0.1433D-03	0.1085D+02	-0.7086D-01	0.1258D+04	0.3085D+02	-0.1461D-03	0.1204D-03
15	-0.1916D-01	-0.1082D-01	-0.4336D-02	0.1024D-02	0.1169D+02	-0.3052D+00	0.7498D+03	-0.4371D+01	0.1244D-02	0.4021D-03
16	-0.1610D-01	-0.1238D-01	0.9703D-02	0.1429D-02	0.1248D+02	-0.6725D+00	0.1007D+04	0.5564D+02	0.1819D-02	0.4511D-03
17	-0.1479D-01	-0.4769D-02	0.1780D-02	-0.1676D-02	0.1320D+02	-0.1164D+01	0.8511D+03	0.3629D+02	-0.2281D-02	0.1498D-03
18	-0.1322D-01	-0.1226D-01	-0.2396D-03	0.1757D-02	0.1381D+02	-0.1784D+01	0.2218D+03	-0.4155D+02	0.2260D-02	0.2539D-03
19	-0.1074D-01	-0.3387D-02	0.2147D-01	0.3501D-03	0.1432D+02	-0.2492D+01			0.7286D-03	0.1367D-03

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUV =	FRWV =	FRAV =
1	0.997591D+01	-0.563363D+00	0.0	0.246631D+04	-0.487898D+03	0.0

REACTIONS AT NODE	RV(LBS)	RW(LBS)	RM(IN-LBS)
1	0.106878D+03	-0.257016D+03	0.0
13	0.397745D+04	-0.127764D+04	0.203428D+04

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.179342D-01	9	2	3	0.126400D-02
2	0.790080D-02	12	1	3	0.133400D-02
INTERFACE	0.529821D-02	10	1	2	0.122600D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.107466D-01	9	1	0.125400D-02	2
2	0.185545D-02	11	2	0.127400D-02	1
INTERFACE	0.161777D-02	13	3	0.125200D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.881166D-02	8	1	0.102200D-02
2	0.494756D-02	13	1	0.133400D-02

CYCLE= 790

ELEMENT	SI STA 1	SO	SI STA 2	SO	SI STA 3	SO
1	0.14507216D-03	0.74626370D-04	-0.36691297D-04	0.17585144D-03	-0.32665095D-04	0.44784669D-03
	0.10784927D-03	0.0	0.69540071D-04	0.0	0.20759080D-03	0.0
2	0.48314869D-03	0.89990453D-05	0.12947659D-02	-0.15308452D-03	0.17930761D-02	-0.57165891D-03
	0.24617387D-03	0.0	0.57084069D-03	0.0	0.61070861D-03	0.0
3	0.24274460D-02	-0.10280379D-02	0.43529594D-02	-0.23981302D-02	0.62580451D-02	-0.35911841D-02
	0.69790403D-03	0.0	0.98091457D-03	0.0	0.13334105D-02	0.0
4	0.70325968D-02	-0.42371385D-02	0.72241760D-02	-0.42422611D-02	0.73448966D-02	-0.42802614D-02
	0.13977291D-02	0.0	0.14909575D-02	0.0	0.15323176D-02	0.0
5	0.64105384D-02	-0.37935617D-02	0.34740983D-02	-0.20386235D-02	0.71437012D-03	-0.40770600D-03
	0.13184884D-02	0.0	0.71773740D-03	0.0	0.15333206D-03	0.0
6	-0.76926531D-03	-0.38494533D-04	-0.45162806D-02	0.24054946D-02	-0.84236324D-02	0.41820204D-02
	-0.40387992D-03	0.0	-0.10553930D-02	0.0	-0.21208060D-02	0.0
7	-0.97184129D-02	0.51661090D-02	-0.89695643D-02	0.46194356D-02	-0.78138593D-02	0.43555806D-02
	-0.21754019D-02	0.0	-0.21750743D-02	0.0	-0.17291393D-02	0.0
8	-0.68278407D-02	0.36013529D-02	-0.52049964D-02	0.24232991D-02	-0.39232446D-02	0.14951590D-02
	-0.17007440D-02	0.0	-0.14308437D-02	0.0	-0.12140428D-02	0.0
9	-0.36730234D-02	0.89357543D-03	-0.42221104D-02	0.15277759D-02	-0.42606071D-02	0.25007534D-02
	-0.13897243D-02	0.0	-0.13471673D-02	0.0	-0.87982692D-03	0.0
10	0.79114173D-03	-0.74313678D-03	0.67751800D-02	-0.40644609D-02	0.52433150D-02	-0.13577317D-01
	0.24062454D-04	0.0	0.13552596D-02	0.0	-0.41670012D-02	0.0
11	-0.11331776D-02	-0.19262110D-03	0.39667859D-03	0.20945738D-03	0.85978168D-03	-0.45541541D-03
12	0.70673179D-03	-0.58904485D-03	0.28290014D-02	-0.22707106D-02	0.48733583D-02	-0.40102901D-02
13	-0.18409472D-02	0.59450086D-03	-0.14115219D-02	-0.44983190D-03	-0.22045139D-03	-0.71072892D-03
	-0.62322317D-03	0.0	-0.93067692D-03	0.0	-0.46559016D-03	0.0
14	0.81192587D-03	-0.16137728D-02	0.11903083D-02	-0.16422218D-02	0.14726302D-02	-0.17832443D-02
	-0.40070096D-03	0.0	-0.22595676D-03	0.0	-0.15930734D-03	0.0
15	0.15152911D-02	-0.18128942D-02	0.12691293D-02	-0.15120024D-02	0.86402494D-03	-0.13577461D-02
	-0.14880153D-03	0.0	-0.12143653D-03	0.0	-0.26161058D-03	0.0
16	-0.47016970D-03	-0.28092061D-03	-0.30202012D-02	0.10975248D-02	-0.52675044D-02	0.28041525D-02
	-0.37554516D-03	0.0	-0.96133823D-03	0.0	-0.12316759D-02	0.0
17	-0.40528571D-02	0.18404457D-02	0.29318155D-03	-0.45465039D-03	0.43870539D-02	-0.30016317D-02
	-0.11062056D-02	0.0	-0.80734421D-04	0.0	0.69271110D-03	0.0
18	0.50342114D-02	-0.31613361D-02	0.30969301D-02	-0.19563931D-02	0.11498833D-02	-0.78464991D-03
	0.93613764D-03	0.0	0.57026850D-03	0.0	0.18261669D-03	0.0

CYCLE= 790

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.42461914D-02	0.15881905D-02	-0.42552450D-02	0.15869313D-02
	-0.14095497D-02	0.0		
2	0.39667859D-03	0.20945738D-03	0.39659994D-03	0.20943545D-03
3	-0.18571183D-02	0.81897387D-03	-0.18588460D-02	0.81863878D-03
	-0.51907224D-03	0.0		

ENERGY AND WORK AT THE END OF TIME CYCLE 790

FRAGMENT	KINETIC ENERGY
1	0.121866D+04

J= 790 TIME (SEC.) = 0.158000D-02 TIME AFTER INITIAL IMPACT = 0.614000D-03
WORK INPUT INTO RING (IN.-LB.) = 0.516582D+03
RING KINETIC ENERGY (IN.-LB.) = 0.502939D+02
RING ELASTIC ENERGY (IN.-LB.) = 0.126456D+03
RING PLASTIC WORK (IN.-LB.) = 0.324631D+03
ENERGY STORED IN THE ELASTIC RESTRAINTS (IN.-LB.) = 0.152012D+02

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	0.0	-0.9104D-02	0.1525D-03	0.0	0.0	0.7106D+03	0.1294D+03	0.2134D-03	0.1356D-03
2	0.2409D-04	-0.9262D-02	-0.9837D-02	0.9400D-04	0.1000D+01	-0.9262D-02	0.8023D+03	0.2547D+03	0.1189D-03	0.2127D-03
3	0.8407D-03	-0.1720D-01	-0.4475D-02	0.1215D-02	0.2001D+01	-0.1720D-01	-0.4411D+02	-0.6904D+03	0.1543D-02	0.2738D-03
4	0.3463D-02	-0.1109D-01	0.2256D-01	0.3892D-02	0.3003D+01	-0.1109D-01	-0.1608D+03	-0.1127D+04	0.5524D-02	0.4534D-04
5	0.6592D-02	0.3586D-01	0.7241D-01	0.1835D-02	0.4007D+01	0.3586D-01	-0.1074D+04	-0.4203D+03	0.5916D-02	0.8646D-04
6	0.4636D-02	0.1259D+00	0.9866D-01	-0.4934D-02	0.5005D+01	0.1259D+00	-0.1959D+04	0.5077D+03	0.1210D-04	-0.2556D-03
7	-0.2140D-02	0.2133D+00	0.6223D-01	-0.7918D-02	0.5998D+01	0.2133D+00	-0.1750D+04	0.5247D+03	-0.7907D-02	-0.3821D-03
8	-0.8104D-02	0.2345D+00	-0.1770D-01	-0.4651D-02	0.6992D+01	0.2345D+00	-0.1423D+04	0.1776D+03	-0.5905D-02	-0.2207D-03
9	-0.1268D-01	0.1883D+00	-0.6909D-01	-0.4797D-02	0.7987D+01	0.1883D+00	-0.8942D+03	-0.3271D+03	-0.2960D-02	-0.7151D-03
10	-0.1939D-01	0.9947D-01	-0.1133D+00	-0.8846D-02	0.8981D+01	0.9947D-01	-0.3489D+04	-0.1726D+03	-0.2914D-02	-0.8020D-03
11	-0.2116D-01	0.1702D-01	-0.1478D-01	-0.1254D-02	0.9979D+01	0.1702D-01	0.3517D+04	-0.7243D+02	-0.7497D-03	-0.2486D-02
12	0.6133D-02	0.8558D-02	-0.1425D-01	-0.1289D-03	0.1050D+02	0.1009D+01	0.3240D+04	-0.1973D+04	0.2017D-03	-0.2564D-03
13	0.0	0.0	0.0	0.4604D-03	0.1150D+02	0.1500D+01	-0.2380D+04	-0.6924D+02	0.2963D-02	-0.2042D-02
14	-0.2329D-01	-0.5908D-02	-0.2322D-01	-0.1822D-03	0.1084D+02	-0.7774D-01	-0.1671D+04	-0.1189D+03	0.2987D-03	-0.5161D-03
15	-0.2040D-01	-0.1991D-01	0.1537D-02	0.7092D-03	0.1168D+02	-0.3133D+00	-0.1347D+04	-0.1058D+03	0.1140D-02	-0.5780D-03
16	-0.1710D-01	-0.1031D-01	0.2585D-01	-0.1680D-03	0.1248D+02	-0.6703D+00	-0.1345D+04	0.3251D+02	0.3967D-03	-0.4057D-03
17	-0.1847D-01	-0.3955D-04	-0.1015D-01	-0.3640D-02	0.1320D+02	-0.1158D+01	-0.5029D+03	-0.3368D+02	-0.4648D-02	-0.3846D-03
18	-0.1577D-01	-0.2015D-01	-0.3620D-02	0.3503D-02	0.1380D+02	-0.1786D+01	-0.1330D+03	-0.1062D+03	0.4668D-02	0.5927D-04
19	-0.1306D-01	-0.1410D-02	0.4054D-01	-0.6649D-03	0.1432D+02	-0.2489D+01			0.2859D-03	-0.2249D-03

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUV =	FRWV =	FRAV =
1	0.100746D+02	-0.592879D+00	0.0	0.246631D+04	-0.487898D+03	0.0

REACTIONS AT NODE	RV(LBS)	RW(LBS)	RM(IN-LBS)
1	-0.816222D+03	-0.345116D+03	0.0
13	0.268815D+04	-0.158427D+04	0.240503D+04

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.179342D-01	9	2	3	0.126400D-02
2	0.790080D-02	12	1	3	0.133400D-02
INTERFACE	0.529821D-02	10	1	2	0.122600D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.107466D-01	9	1	0.125400D-02	2
2	0.185545D-02	11	2	0.127400D-02	1
INTERFACE	0.161777D-02	13	3	0.125200D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.881166D-02	8	1	0.102200D-02
2	0.494756D-02	13	1	0.133400D-02

THE LARGEST COMPUTED STRAINS FOR EACH SUBSTRUCTURE-- MAIN AND BRANCHES -- ARE PRINTED BELOW. 1= INNER 2= OUTER SURF

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.179342D-01	9	2	3	0.126400D-02
2	0.790080D-02	12	1	3	0.133400D-02
INTERFACE	0.529821D-02	10	1	2	0.122600D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.107466D-01	9	1	0.125400D-02	2
2	0.185545D-02	11	2	0.127400D-02	1
INTERFACE	0.161777D-02	13	3	0.125200D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.881166D-02	8	1	0.102200D-02
2	0.494756D-02	13	1	0.133400D-02

NO CARDS PUNCHED DURING THIS RUN FOR CONTINUATION.

REFERENCES

1. Wu, R.W.H., and Witmer, E.A., "Finite-Element Analysis of Large Transient Elastic-Plastic Deformations of Simple Structures, with Application to the Engine Rotor Fragment Containment/Deflection Problem", ASRL TR 154-4, MIT, January 1972 (Available as NASA CR-120886).

2. Wu, R.W.H., and Witmer, E.A., "Computer Program JET 3 - to Calculate the Large Elastic-Plastic Dynamically-Induced Deformations of Free and Restrained, Partial and/or Complete Structural Rings", ASRL TR 154-7, MIT, August 1972 (Available as NASA CR-120993).

3. Collins, T.P., and Witmer, E.A., "Application of the Collision-Imparted Velocity Method for Analyzing the Responses of Containment and Deflector Structures to Engine Rotor Fragment Impact", ASRL TR 154-8, MIT, August 1973 (Available as NASA CR-134494).

4. Stagliano, T.R., Spilker, R.L. and Witmer, E.A., "User's Guide to Computer Program CIVM-JET 4B to Calculate the Transient Structural Responses of Partial and/or Complete Structural Rings to Engine-Rotor-Fragment Impact", ASRL TR 154-9, MIT, March 1976 (Available as NASA CR-134907).

5. Goldsmith, W., Impact: The Theory and Physical Behavior of Colliding Solids, Edward Arnold (Publishers) Ltd., London, 1960.

6. Selby, S.M. (Editor-in-Chief of Mathematics), CRC Standard Mathematical Tables, 20th Edition, CRC Press, Cleveland, Ohio, 1972, p. 106.

7. Cowper, G.R. and Symonds, P.S., "Strain-Hardening and Strain-Rate Effects in the Impact Loading of Cantilever Beams", Tech. Report No. 28, ONR Contract Nonr-562(10), NR-064-406, Div. of Appl. Math., Brown University, Sept. 1957.

8. Ting, T.C.T., "The Plastic Deformation of a Cantilever Beam with Strain Rate Sensitivity under Impulsive Loading", Brown University TR 70, Contract Nonr-562(10), July 1961.

9. Isbell, W.M., Christman, D.R., Babcock, S.G., Michaels, T.E., and Green, S.G., "Measurements of Dynamic Properties of Materials, Vol. I: Summary of Results", General Motors Materials and Structures Laboratory, DASA-2501-1 (MSL-70-23, Vol. 1), July 1970.

10. Holt, D.L., Babcock, S.G., Green, S.J., and Maiden, C.J., "The Strain Rate Dependence of the Flow Stress in Some Aluminum Alloys", Transactions of the ASM, Vol. 60, No. 2, June 1967, pp. 152-159.

11. Eleiche, A-S.M., "A Literature Survey of the Combined Effects of Strain Rate and Elevated Temperature on the Mechanical Properties of Metals", AFML-TR-72-125, Sept. 1972.

12. Hoggatt, C.R. and Recht, R.F., "Stress-Strain Data Obtained at High Strain Rates Using an Expanding Ring", Experimental Mechanics, Vol. 9, No. 10, Oct. 1969, pp. 441-448.

13. McClellan, D.L., "Constitutive Equations for Mechanical Properties of Structural Materials", AIAA Journal, Vol. 5, No. 3, March 1967, pp. 446-450.

14. Hildebrand, F.B., Introduction to Numerical Analysis, McGraw-Hill Book Co., New York, Second Edition, 1974.

15. Lowan, A.N., Davids, N. and Levenson, A., "Table of the Zeros of the Legendre Polynomials of Order 1-16 and the Weight Coefficients for Gauss' Mechanical Quadrature Formula", Bulletin of the American Mathematical Society, Vol. 48, No. 10, Oct. 1942, pp. 739-743.

16. Abramowitz, M. and Stegun, L.A. (Editors), Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables, U.S. Dept. of Commerce, National Bureau of Standards, Applied Math. Series 55, November 1970, pp. 916-919.

17. Zienkiewicz, O.C., The Finite Element Method in Engineering Science, McGraw-Hill Book Co., London, 1971.

TABLE

EXAMPLE PROBLEM RESULTS OBTAINED FROM SEVERAL SYSTEMS, COMPILERS, AND PROGRAM MODIFICATIONS FOR JET 5A AND CIVM-JET 5B (SEE SUBSECTIONS 7.1 AND 7.2)

PROGRAM	SYSTEM	COMPILER	J	TIME (SEC)	REACTIONS AT NODE 1			REACTIONS AT NODE 21			LARGEST STRAINS FOR EACH SUBSTRUCTURE					
					RV (LBS)	RW (LBS)	RM (IN-LBS)	RV (LBS)	RW (LBS)	RM (IN-LBS)	SUBS.	MSTR	ELE	SURF	STA	TIME (SEC)
JET 5A	IBM 370	G EXTEN AT MIT	150	0.000600	15026.1	0.0	15223.0	36925.5	0.0	-12355.7	1	0.123908	9	2	1	0.000600
	IBM 360	H EXTEN[b]	150	0.000600	15026.1	0.0	15223.0	36925.5	0.0	-12355.7	1	0.123908	9	2	1	0.000600
		H EXTEN[a,b]	150	0.000600	15026.1	0.0	15223.0	36925.5	0.0	-12355.7	1	0.123908	9	2	1	0.000600
		TSS[a,b]	150	0.000600	9304.59	0.0	15939.1	38072.8	0.0	-11465.6	1	0.124536	9	2	1	0.000600
	UNIVAC 1100/42	FOR.V[a,b,c]	150	0.000600	5044.37	0.0	16854.9	33979.1	0.0	-12119.5	1	0.124189	9	2	1	0.000600
		ASCII[a,b]	150	0.000600	12396.0	0.0	15788.8	29090.4	0.0	-11940.2	1	0.123941	9	2	1	0.000600
					REACTIONS AT NODE 1			REACTIONS AT NODE 13								
CIVM-JET 5B	IBM 370	G EXTEN AT MIT	790	0.001580	-816.222	-345.116	0.0	2688.15	-1584.27	2405.03	1	0.0179342	9	2	3	0.001264
	IBM 360	H EXTEN[b]	790	0.001580	-816.222	-345.116	0.0	2688.15	-1584.27	2405.03	1	0.0179342	9	2	3	0.001264
		H EXTEN[a,b]	790	0.001580	-816.222	-345.116	0.0	2688.15	-1584.27	2405.03	1	0.0179342	9	2	3	0.001264
		TSS[a,b]	790	0.001580	-585.535	-321.497	0.0	2767.64	-1642.0	2477.13	1	0.0177578	9	2	3	0.001262
	UNIVAC 1100/42	ASCII[a,b]	790	0.001580	-237.605	-344.243	0.0	3269.89	-1635.11	2522.31	1	0.0178627	9	2	3	0.001262

a: NASA-Lewis elimination of nested indices.
b: NASA-Lewis addition of special symbol for index retention in subprogram PRINT.
c: NASA-Lewis segmentation (overlay).

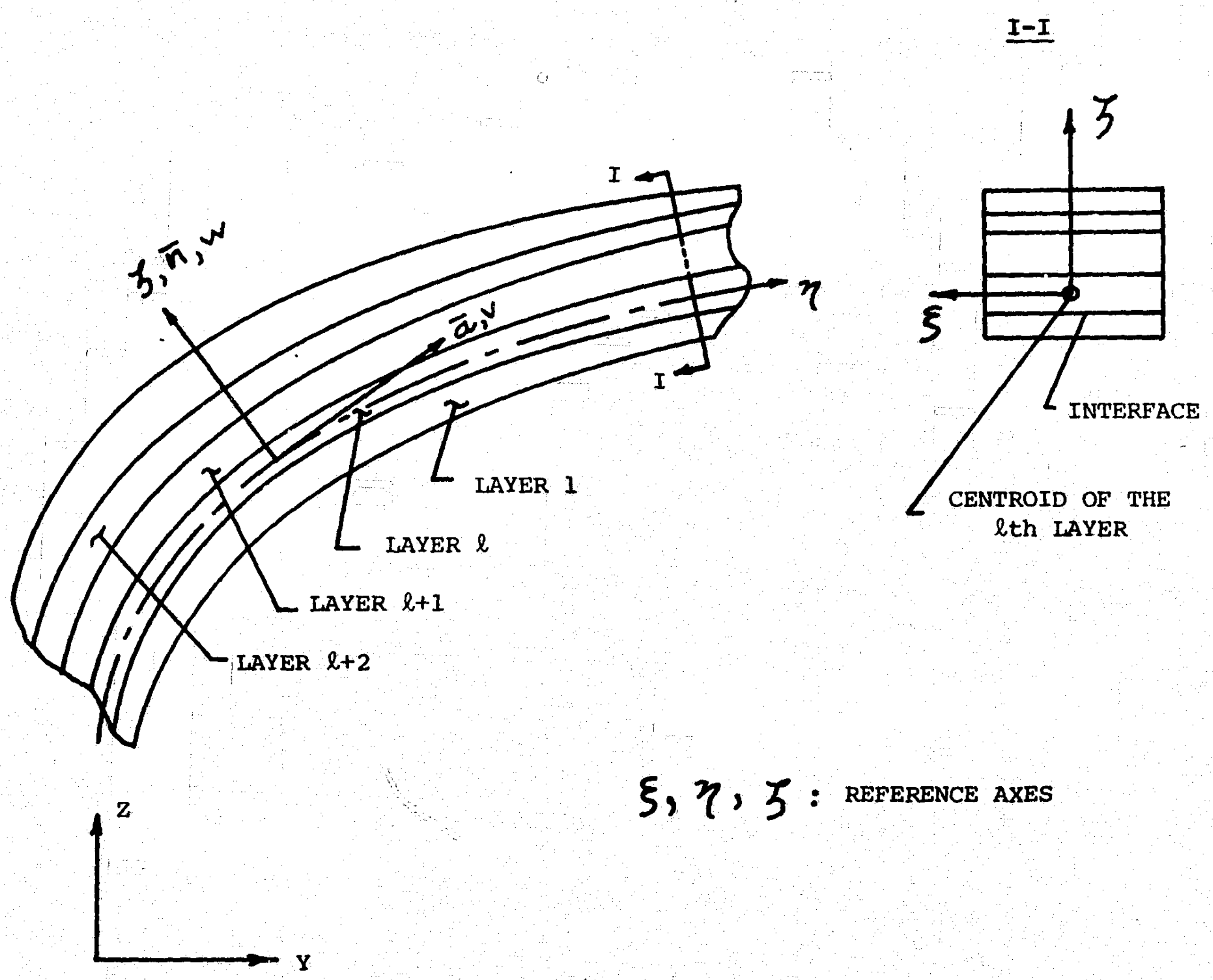

FIG. 1 ILLUSTRATION OF A MULTILAYER VARIABLE-THICKNESS, ARBITRARILY-CURVED BEAM

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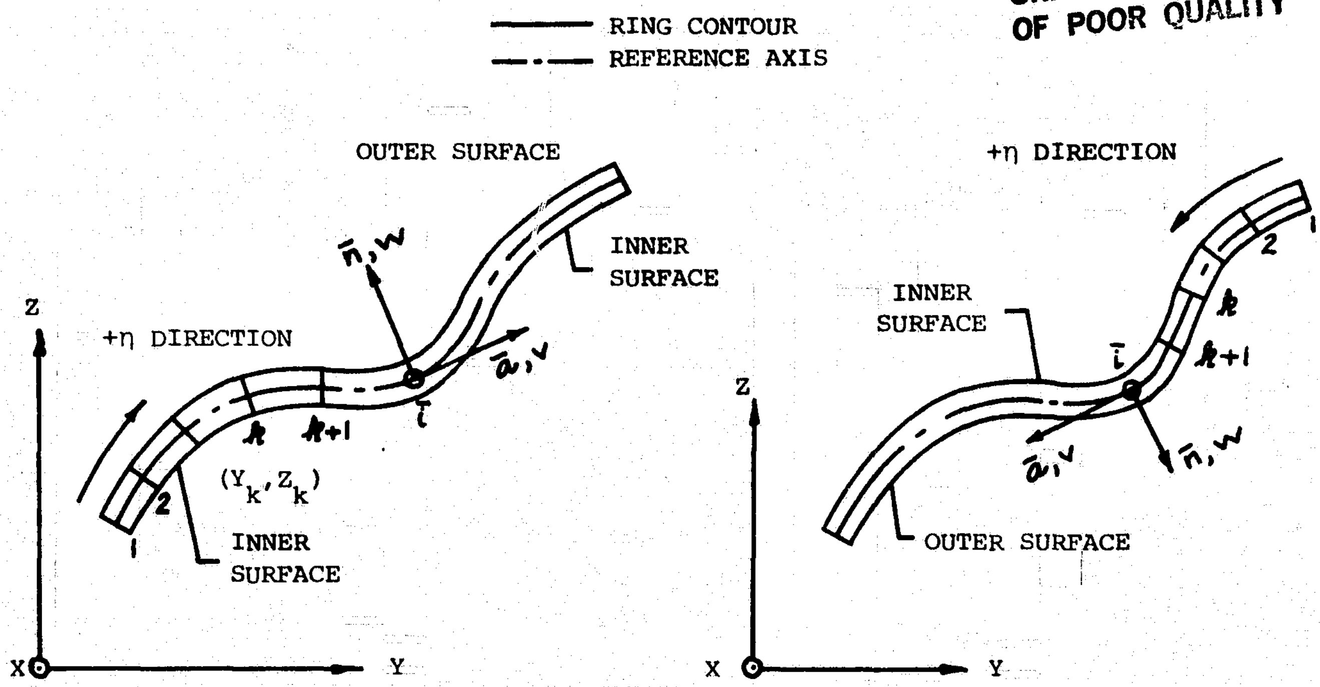
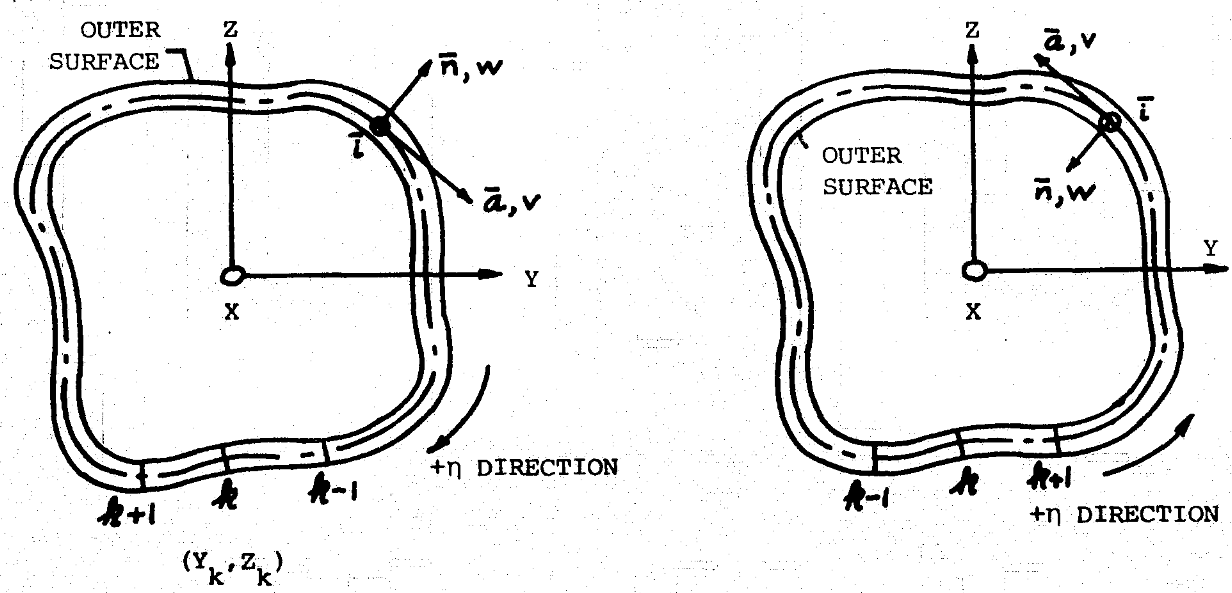
OF POOR QUALITY

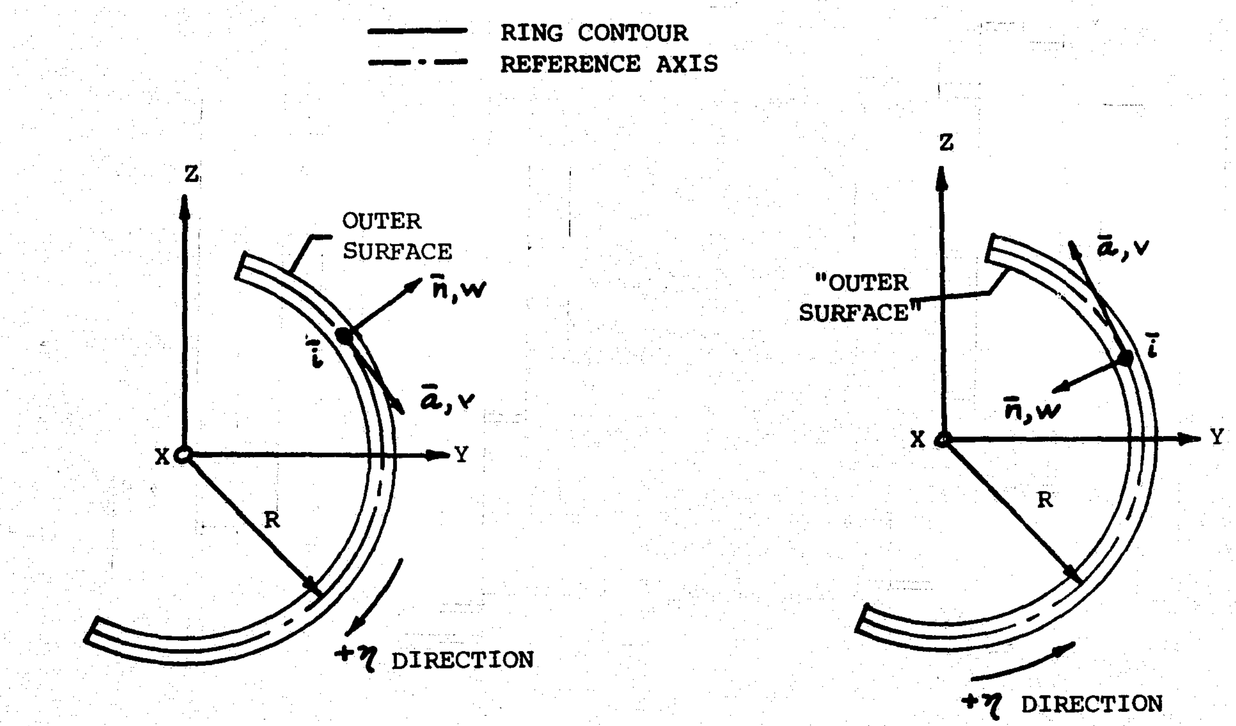


(a) Variable-Thickness Arbitrarily-Curved Partial Ring

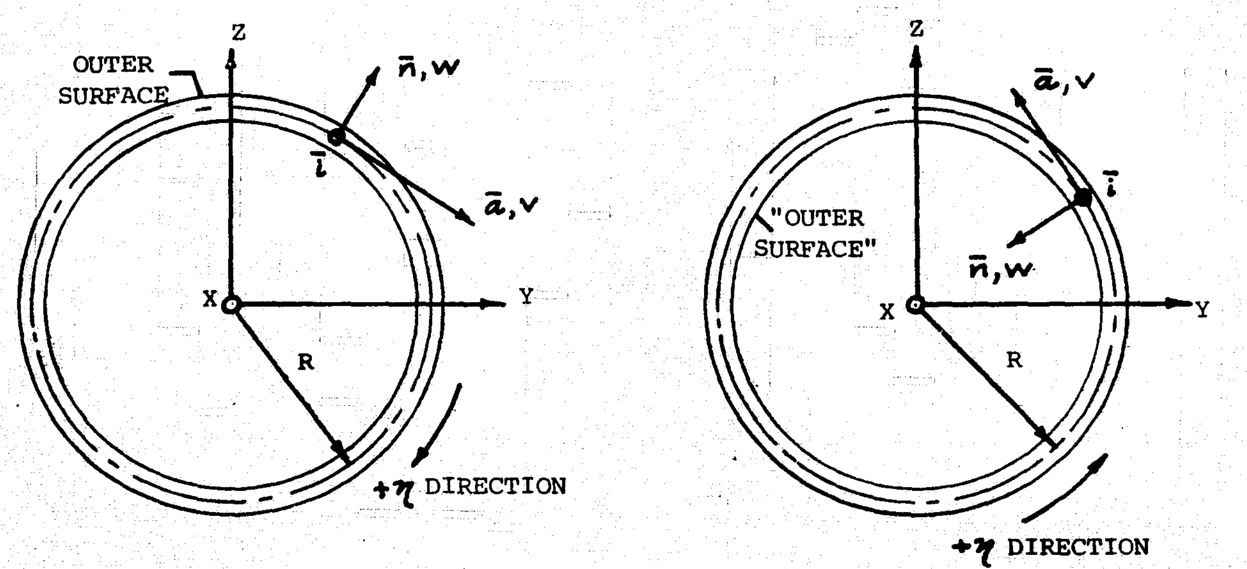


(b) Variable-Thickness Arbitrarily-Curved Complete Ring

FIG. 2 EXAMPLE GEOMETRICAL SHAPES OF STRUCTURAL RINGS ANALYZED BY THE JET 5 PROGRAM



(C) Variable-Thickness Partial Circular Ring



(d) Variable-Thickness Complete Circular Ring

FIG. 2 CONCLUDED

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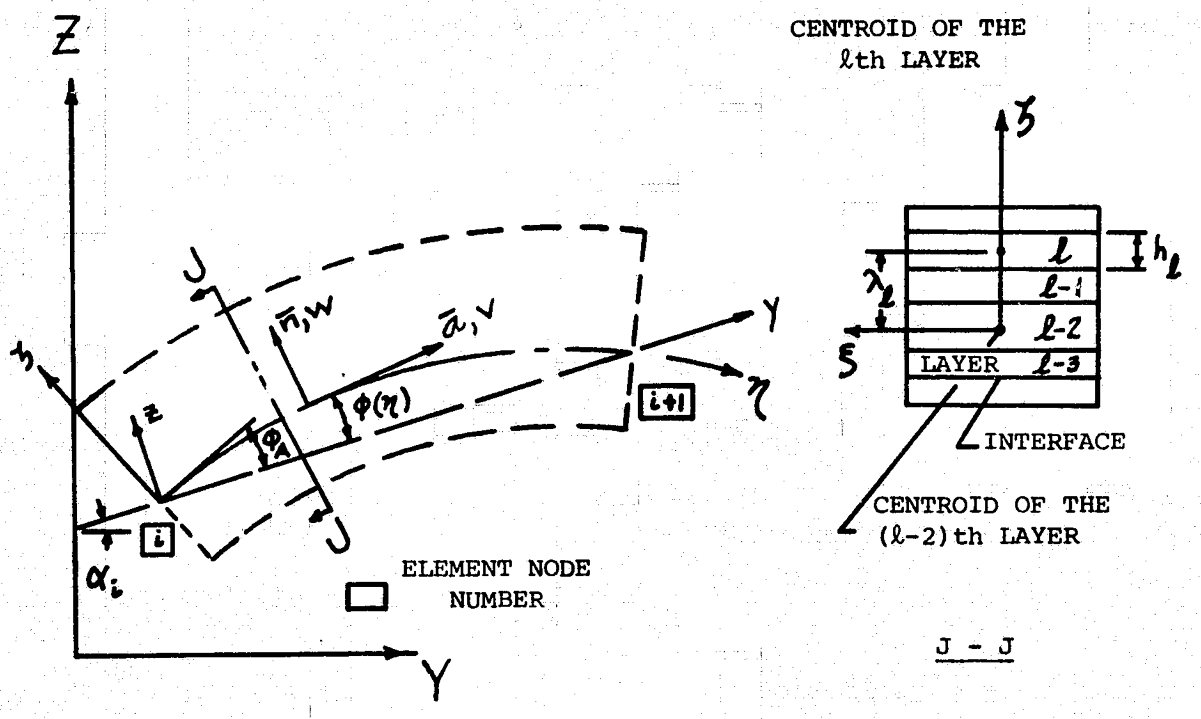
OF POOR QUALITY



$$-15^\circ \lesssim \phi_{i+1} - \phi_i \leq 0$$

$$-180^\circ < \phi_i \leq 180^\circ$$

$$\phi(\eta) = b_0 + b_1\eta + b_2\eta^2$$

$$h_\ell = h_{i,\ell}\left(1 - \frac{\eta}{\eta_i}\right) + h_{i+1,\ell}\frac{\eta}{\eta_i}$$

LOCAL SYSTEM

ξ, η, ζ: COORDINATES

v, w, ψ, χ: DISPLACEMENTS

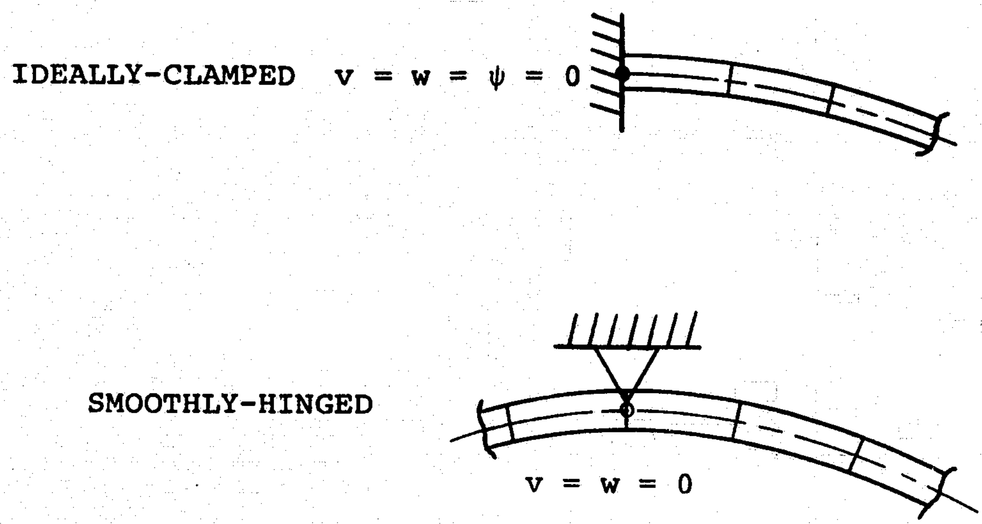
$q_1, q_2, \ldots q_8$: ELEMENT GENERALIZED DISPLACEMENTS

CARTESIAN REFERENCE

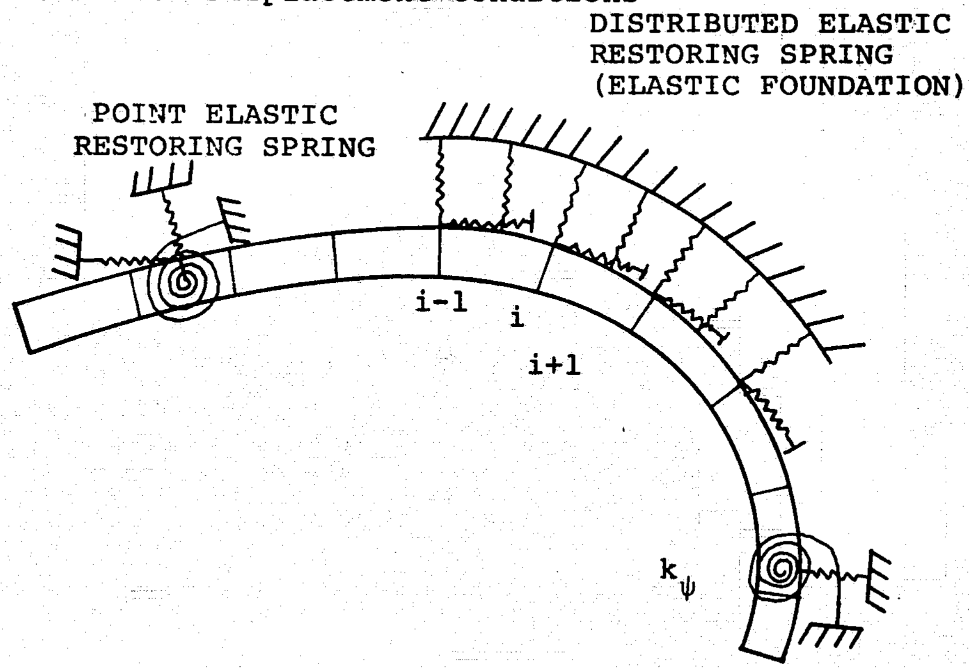
Y, Z: GLOBAL COORDINATES

y, z: LOCAL COORDINATES

FIG. 3 NOMENCLATURE FOR GEOMETRY, COORDINATES, AND DISPLACEMENTS OF A MULTILAYER CURVED-BEAM FINITE ELEMENT

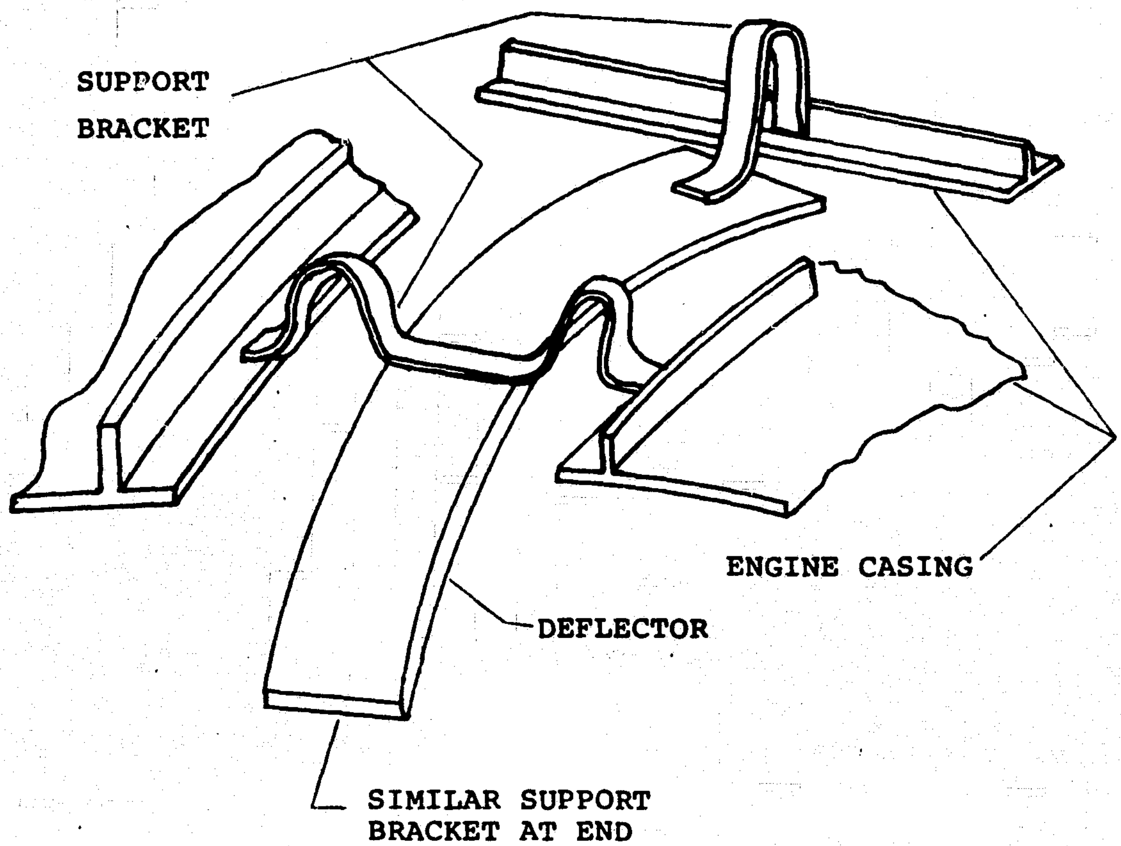


(a) Prescribed Displacement Conditions



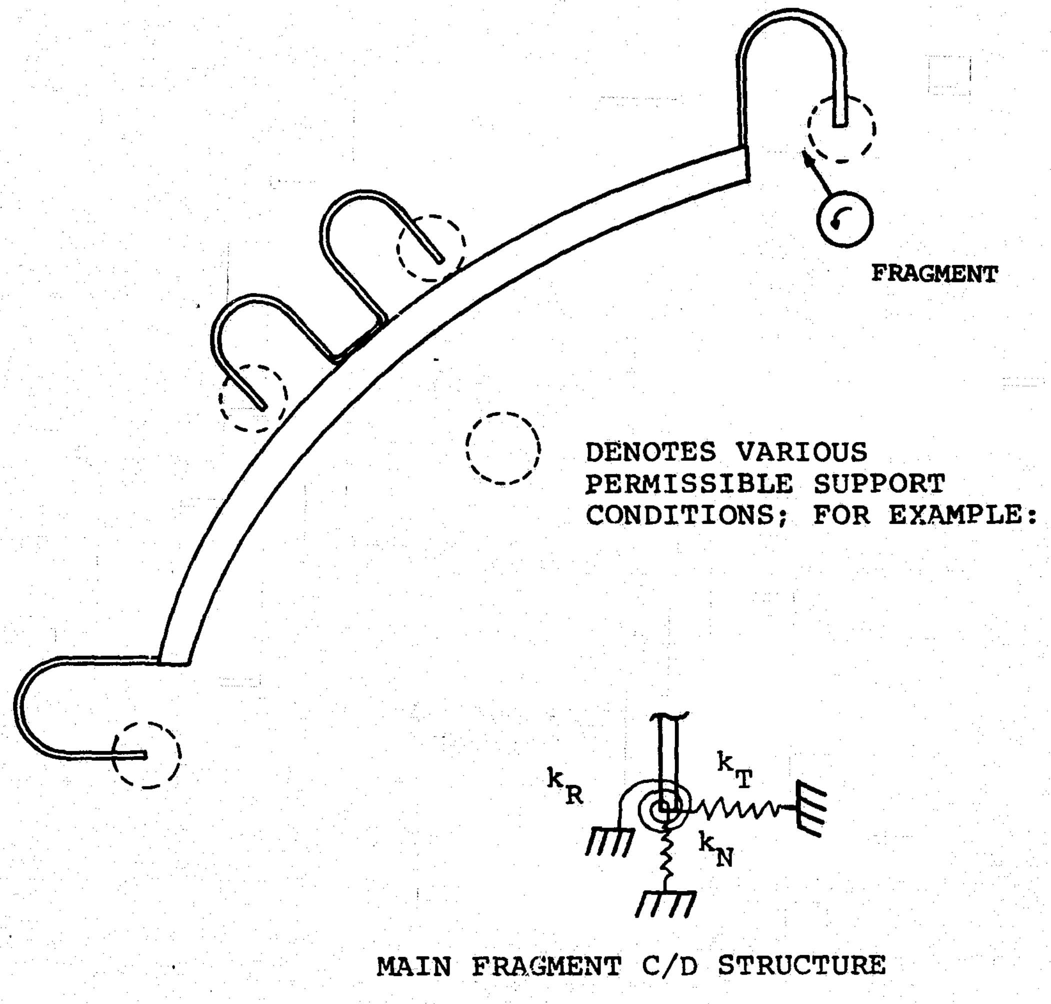
(b) Elastic Restraints

FIG. 4 SCHEMATICS FOR THE SUPPORT CONDITIONS OF THE STRUCTURE



(c) Schematic of a Bracket-Supported Fragment Containment/ Deflector Structure

FIG. 4 CONTINUED



(d) Idealized Two-Dimensional Model of the Configuration Depicted in (c)

FIG. 4 CONCLUDED

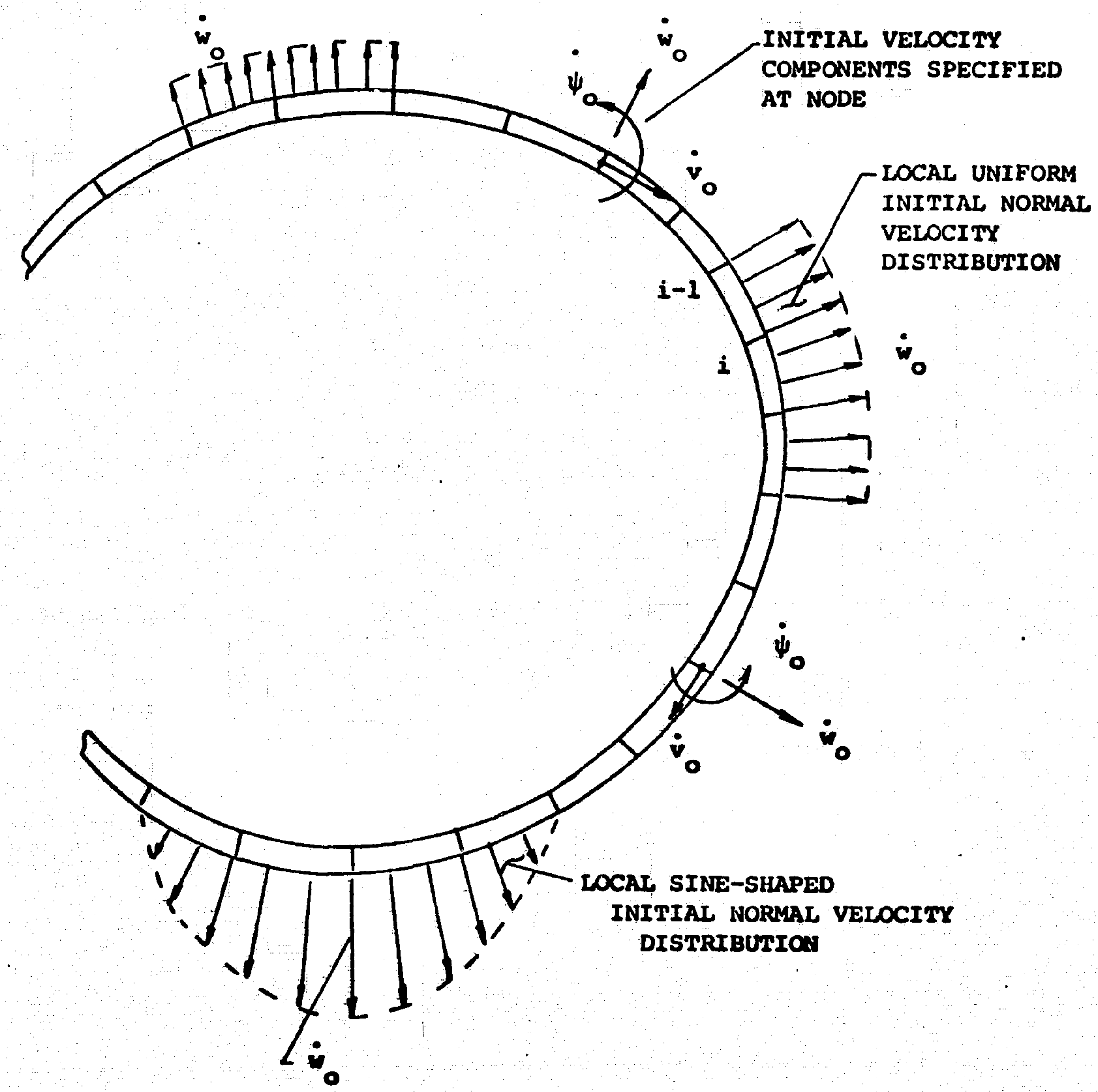
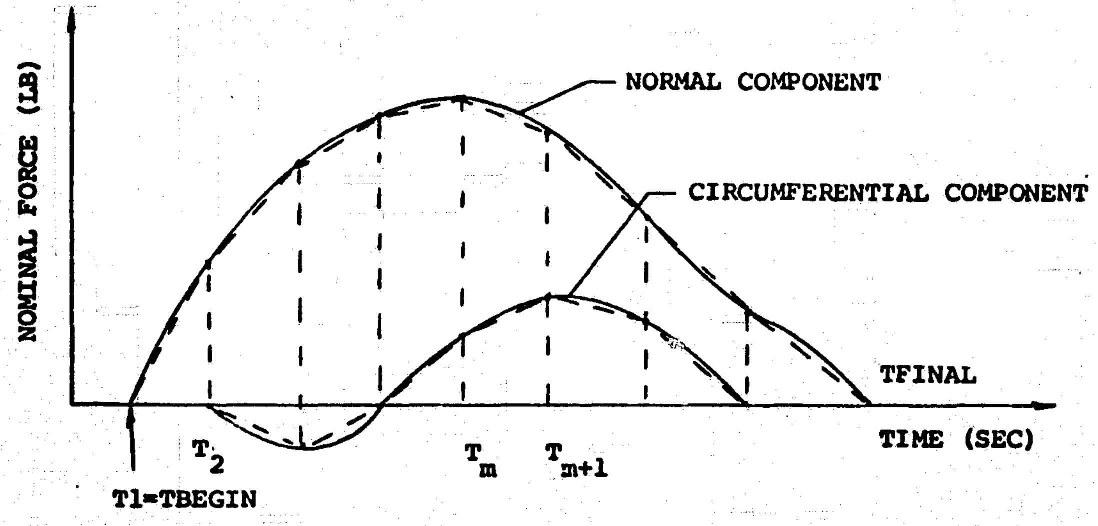
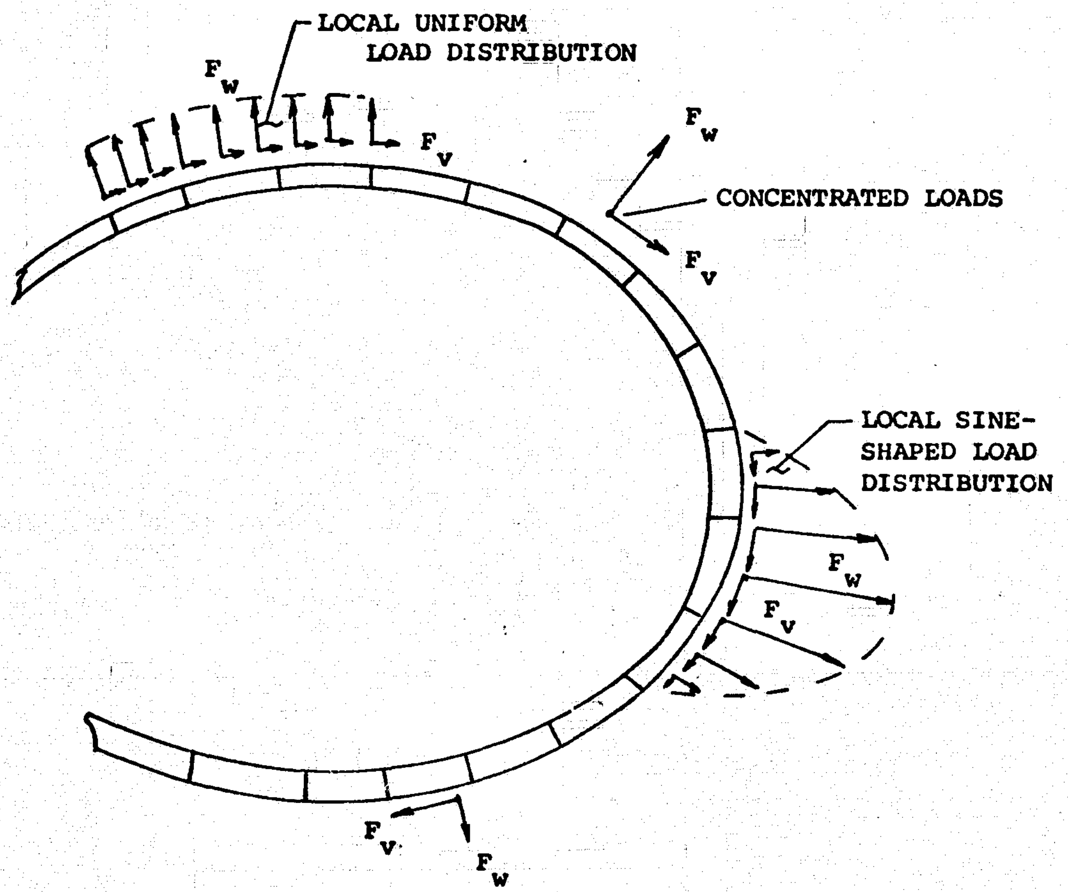


FIG. 5 SCHEMATIC OF INITIAL-VELOCITY PROVISIONS

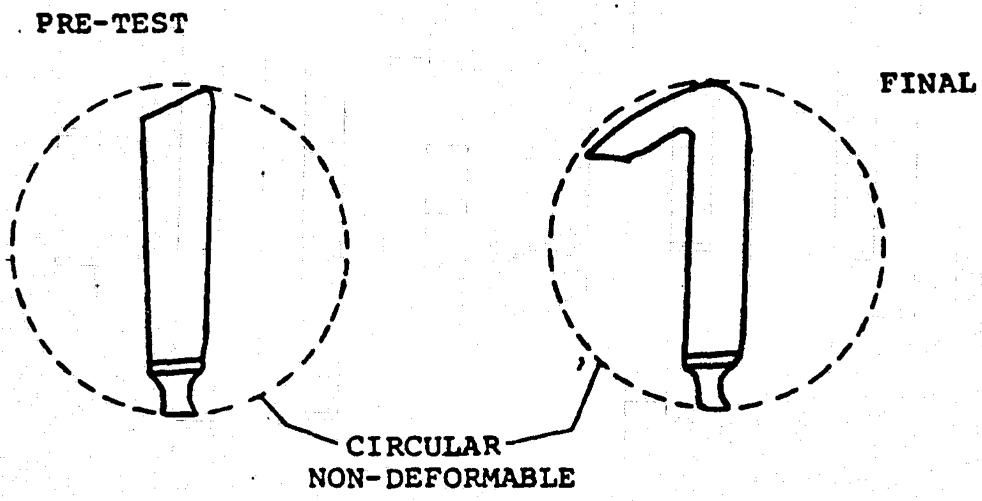


(a) "Nominal Force" Component Time History

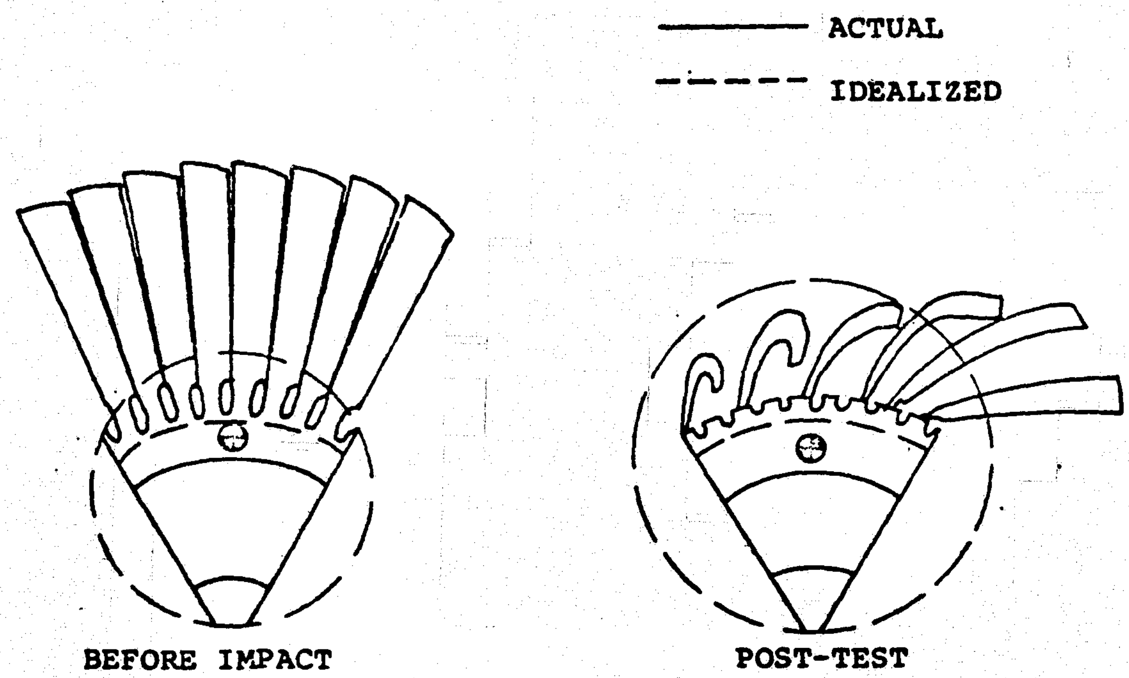


(b) Spatial Force Distribution

FIG. 6 TIME HISTORY AND SPATIAL DISTRIBUTIONS OF THE EXTERNALLY-APPLIED LOADINGS



(a) Single Blade Fragment



(b) Bladed-Disk Type Fragment

FIG. 7 SCHEMATICS OF ACTUAL AND IDEALIZED FRAGMENTS

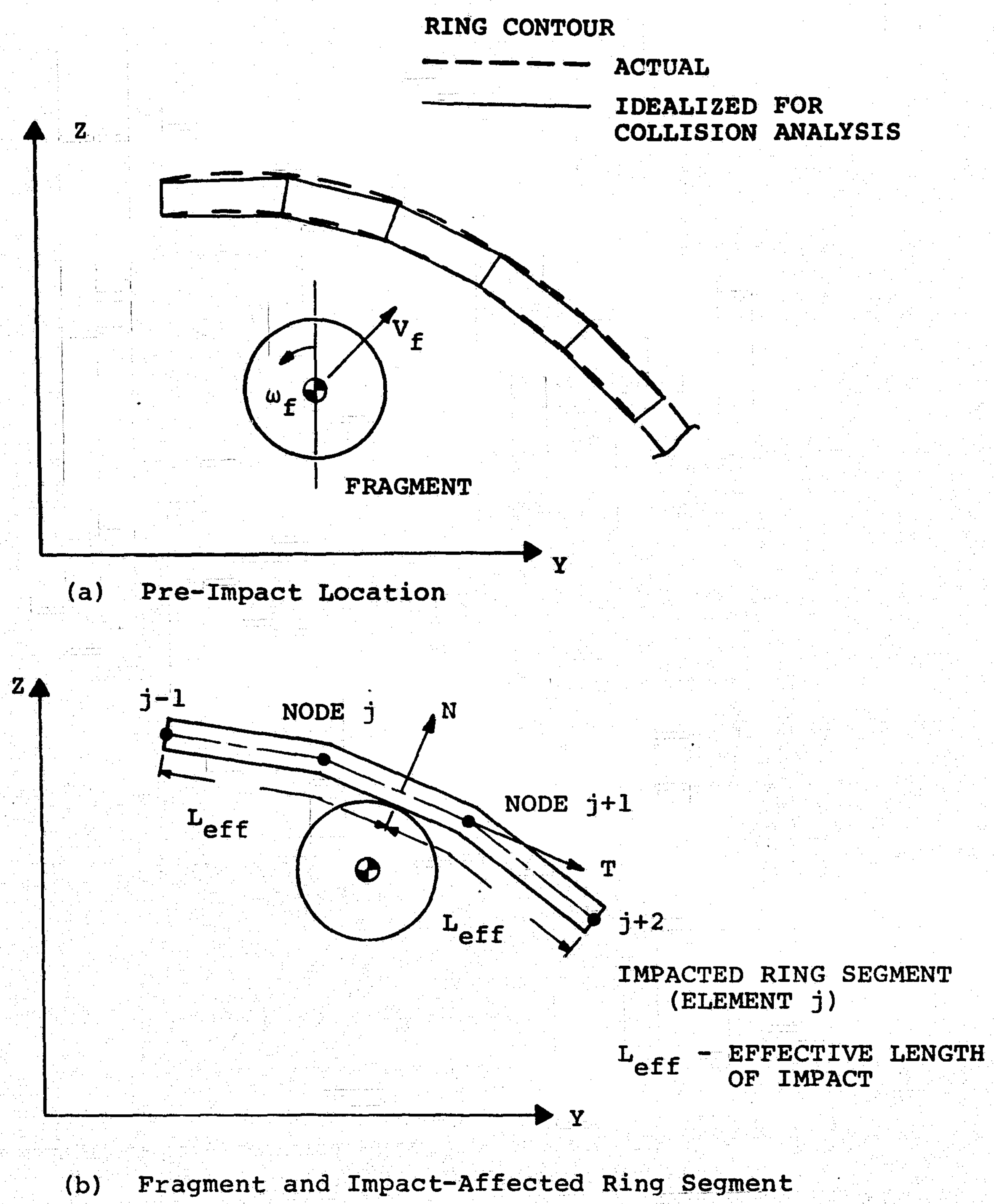


FIG. 8 IDEALIZATION OF RING CONTOUR FOR COLLISION ANALYSIS

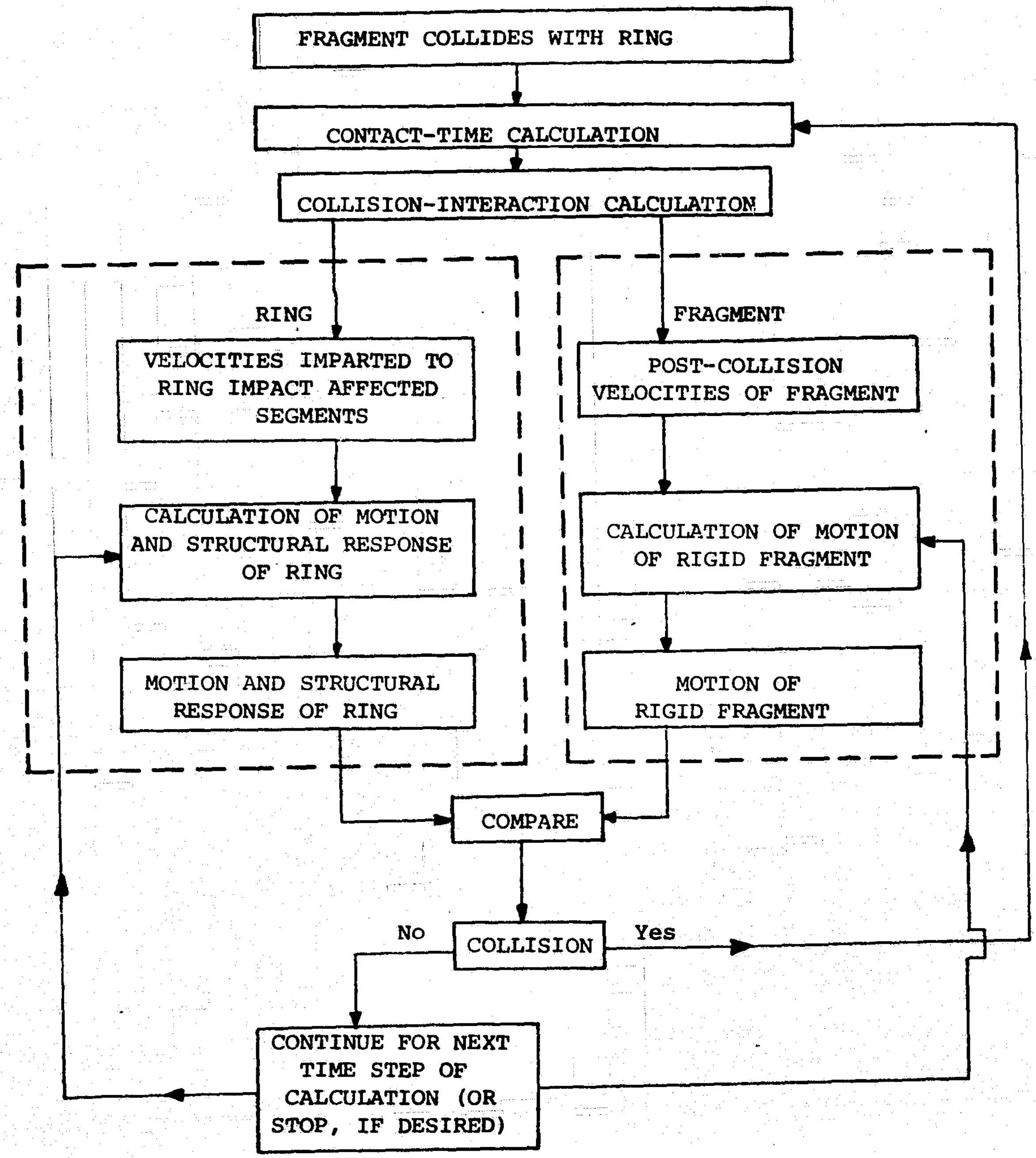
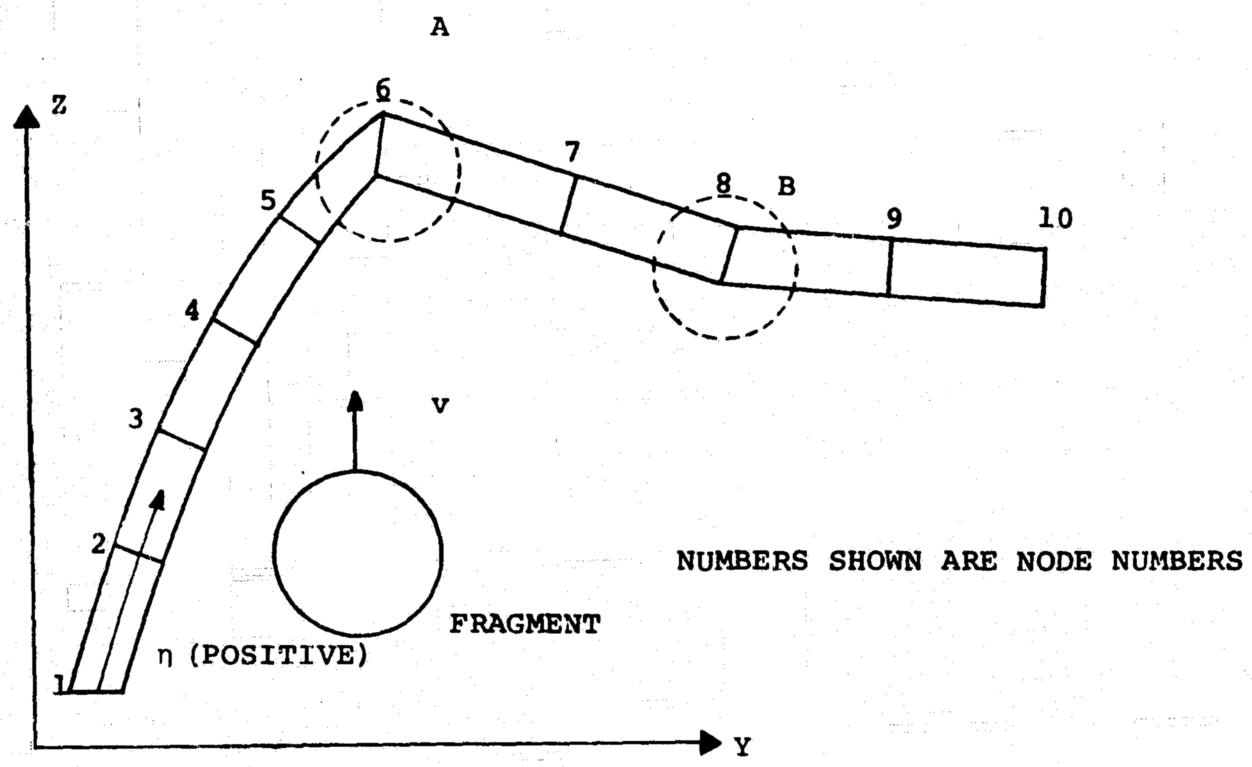
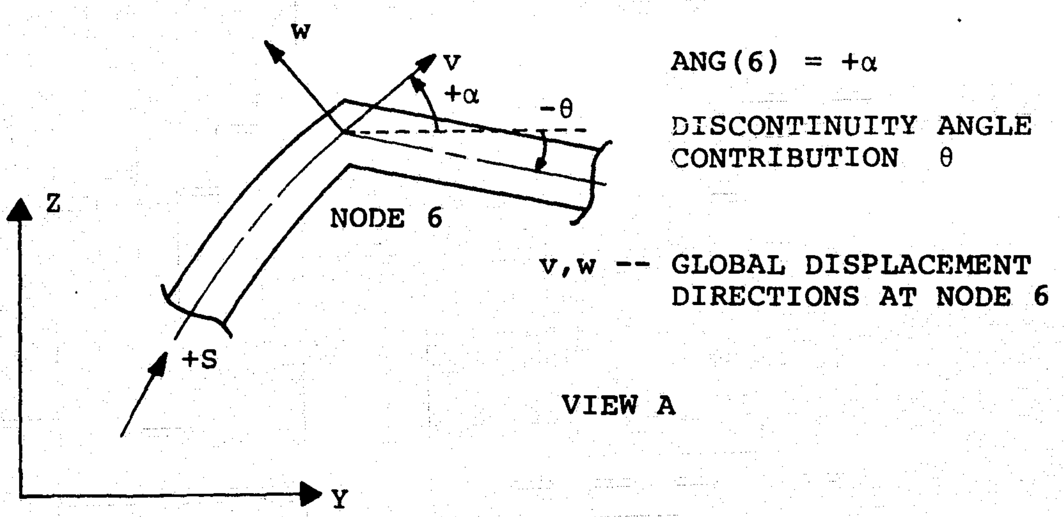


FIG. 9 INFORMATION FLOW SCHEMATIC FOR PREDICTING RING AND FRAGMENT MOTIONS IN THE COLLISION-IMPARTED VELOCITY METHOD

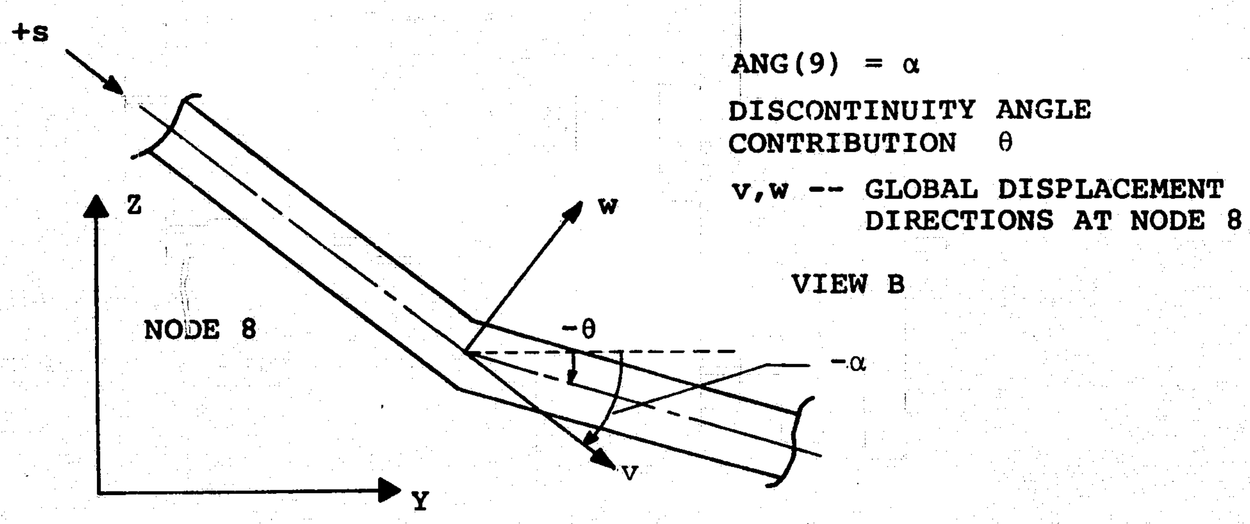


(a) Illustrative Fragment C/D Structure with Slope Discontinuities



(b) Exploded View of Node 6 -- Angle Definitions

FIG. 10 DEFINITION OF SLOPE-DISCONTINUITY ANGLES FOR AN ILLUSTRATIVE FRAGMENT AND C/D STRUCTURE



(c) Exploded View of Node 8 -- Angle Definitions

FIG. 10 CONCLUDED

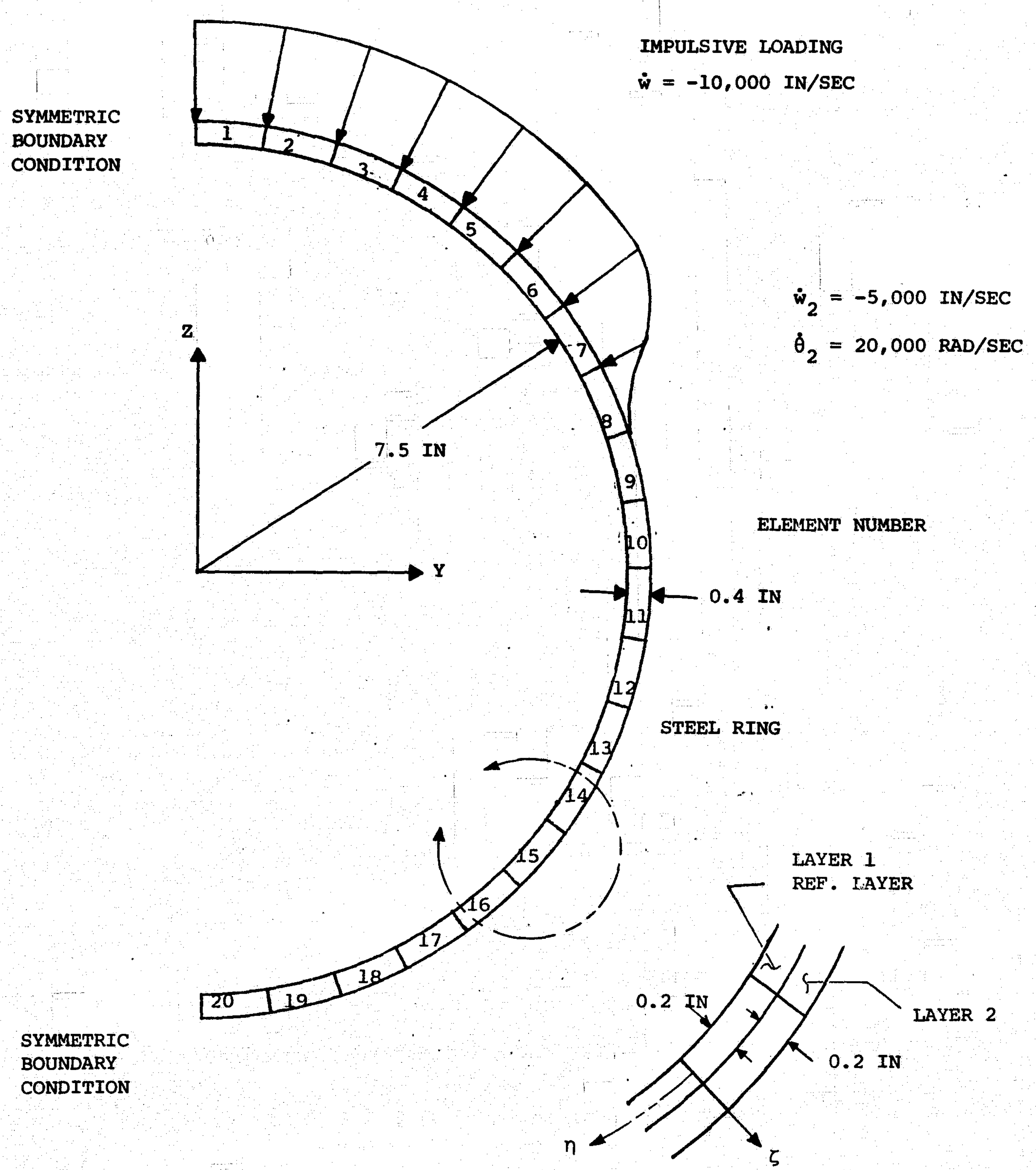
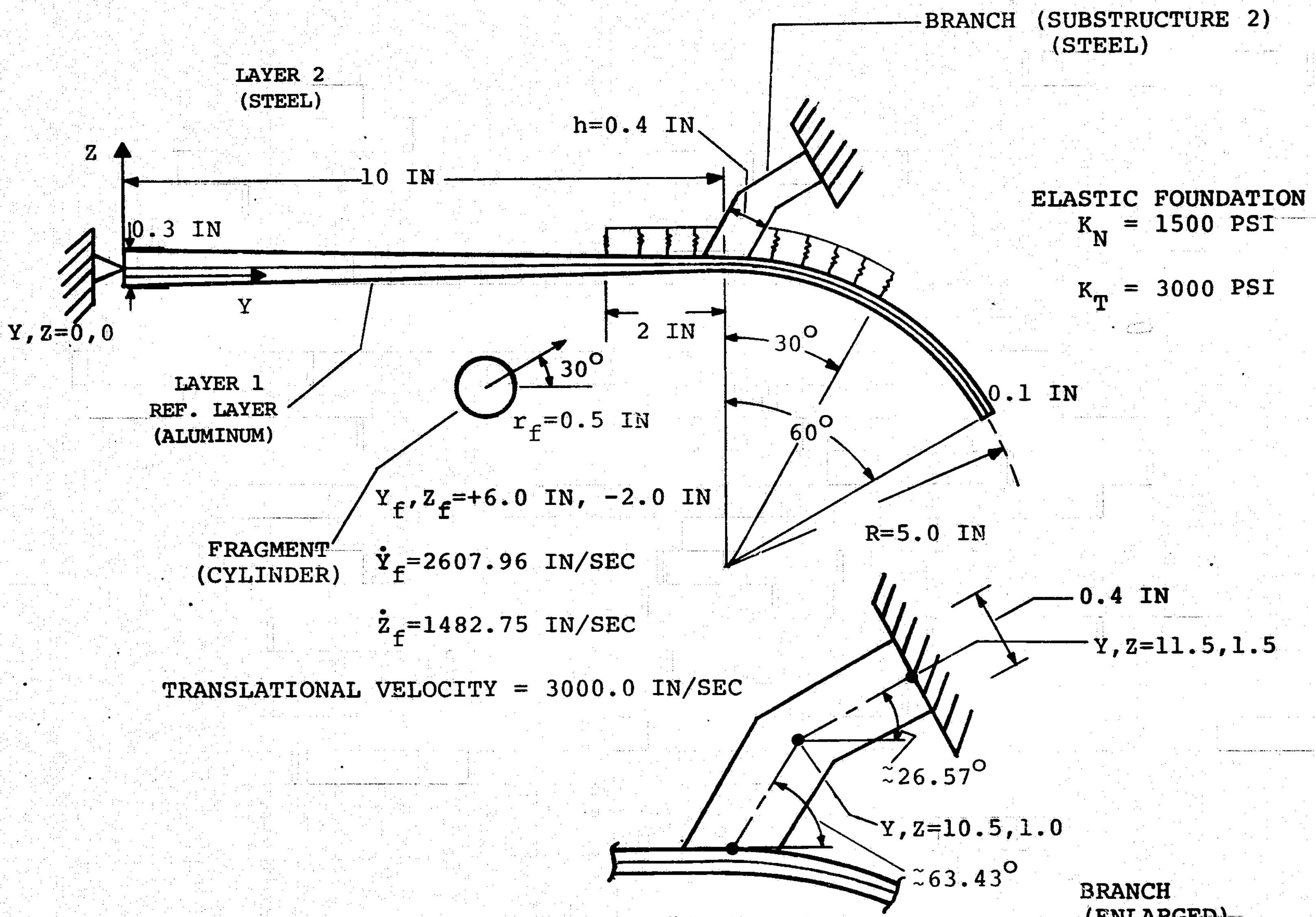
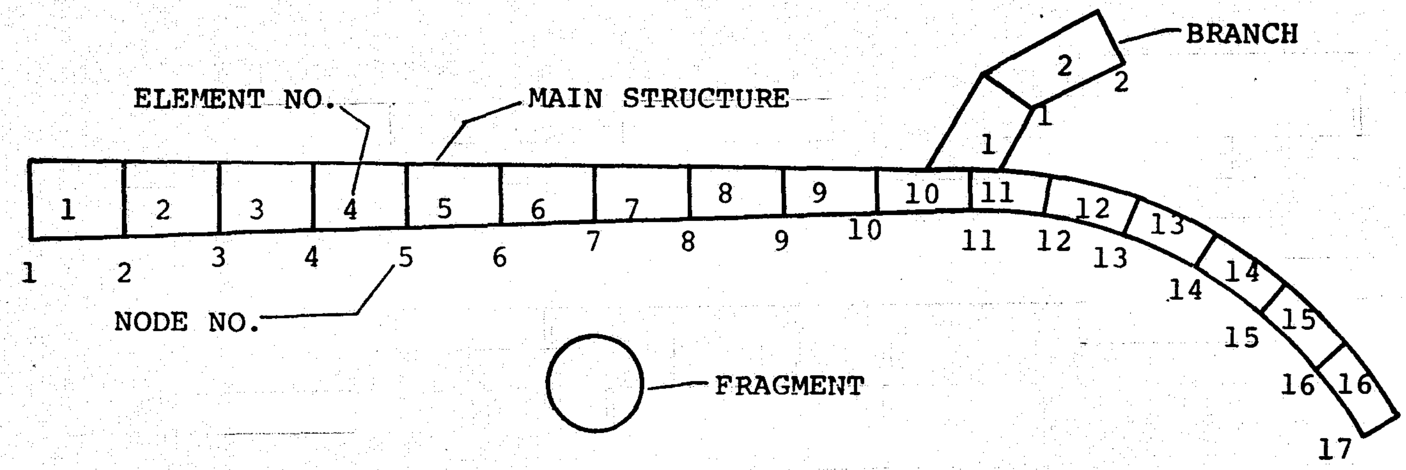


FIG. 11 PROBLEM DATA, GEOMETRY, NOMENCLATURE, AND FINITE-ELEMENT MODELING FOR THE JET 5A EXAMPLE



(a) Geometry and Nomenclature

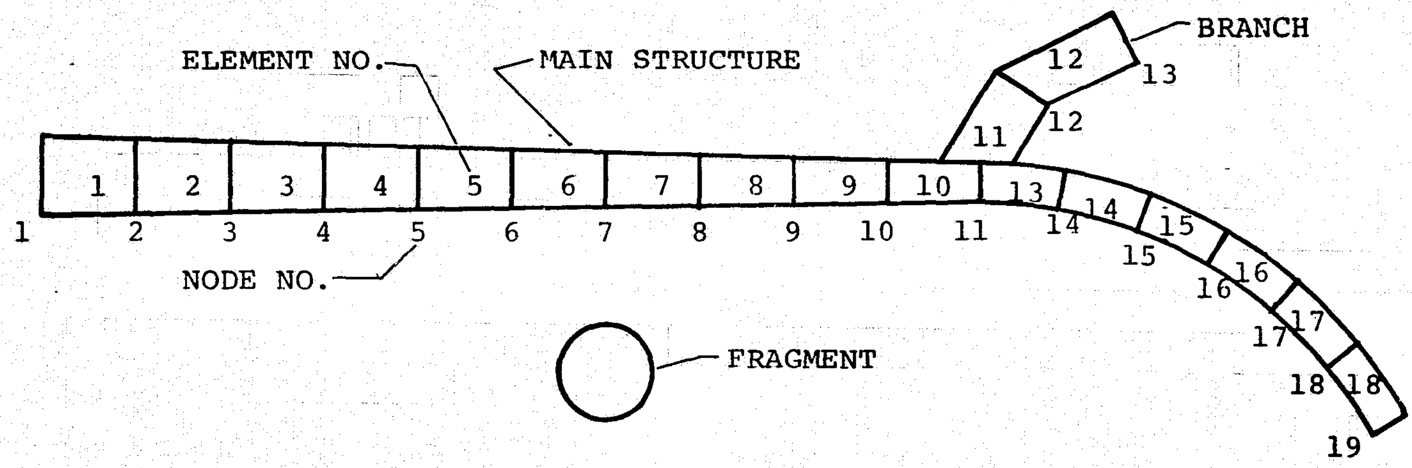
FIG. 12 PROBLEM DATA, GEOMETRY, NOMENCLATURE, AND FINITE-ELEMENT MODELING FOR THE CIVM-JET 5B EXAMPLE



NOTE: NODAL NUMBERS USED FOR B.C.'S ARE FOUND ON THIS FIGURE.

(b) User-Generated Numbering System

FIG. 12 CONTINUED



NOTE: USER MUST GENERATE ELASTIC FOUNDATION NUMBERS FROM THIS NUMBERING SCHEME. ELASTIC FOUNDATION #1 COVERS ELEMENTS 9 AND 10. ELASTIC FOUNDATION #2 COVERS ELEMENTS 13, 14, AND 15. SEE PAGE 52 AND CARD 16BB FOR EXPLANATION.

(c) Computer Generated Global Numbering System

FIG. 12 CONCLUDED

APPENDIX A

GOVERNING EQUATIONS ON WHICH JET 5A IS BASED

A.1 Formulation for Variable-Thickness Arbitrarily-Curved Multilayer Beam Elements and Structures

The geometry and nomenclature of a typical curved multilayer beam discrete element are shown in Fig. 3, where the deformation plane is η,ζ and the coordinates η along and ζ normal to the centroidal axis of a conveniently-chosen layer are employed as the reference coordinates of the multilayer-beam element. The slope, ϕ, of the reference circumferential axis, which is the angle between the tangent vector and the y-axis of the local-reference Cartesian coordinate may be approximated by a second degree polynomial in η as follows:

$$\phi(\eta) = b_o + b_1 \eta + b_2 \eta^2 \tag{A.1}$$

where the constants b_o, b_1, and b_2 can be determined from the known initial geometry of the curved beam element. Assume that the change in element slope between nodes i and i+1 is small so that

$$\cos(\phi_{i+1} - \phi_i) \doteq 1 \tag{A.2a}$$

and

$$\sin(\phi_{i+1} - \phi_i) \doteq \phi_{i+1} - \phi_i \tag{A.2b}$$

This restricts the slope change within an element to $\lesssim$ 15 degrees. The arc length, η_i, of the element is approximated to be the same as the length of a circular arc passing through the nodal points at the slopes ϕ_i and ϕ_{i+1}; η_i is given by

$$\eta_i = \frac{L_i (\phi_{i+1} - \phi_i)}{2 \sin\left(\frac{\phi_{i+1} - \phi_i}{2}\right)} \tag{A.3}$$

where L_i is the length of the chord joining nodes i and i+1 and is given by

$$L_i = \left[(Z_{i+1} - Z_i)^2 + (Y_{i+1} - Y_i)^2 \right]^{\frac{1}{2}} \qquad \text{(A.3a)}$$

and Y_i and Z_i are the initial Y and Z coordinates, respectively, of the ith node. The three constants in Eq. A.1 are then determined from the relations

$$\begin{aligned} \phi(\eta=0) &= \phi_i \\ \phi(\eta=\eta_i) &= \phi_{i+1} \\ \int_0^{\eta_i} \sin\phi \, d\eta &\doteq \int_0^{\eta_i} \phi \, d\eta = 0 \end{aligned} \qquad \text{(A.4)}$$

From Eq. A.4, the constants in Eq. A.1 are found to be

$$\begin{aligned} b_0 &= \phi_i \\ b_1 &= -2(\phi_{i+1} + 2\phi_i)/\eta_i \\ b_2 &= 3(\phi_{i+1} + \phi_i)/(\eta_i)^2 \end{aligned} \qquad \text{(A.5)}$$

Accordingly, the radius of curvature, R, of the centroidal axis may be expressed as $R = -(d\phi/\partial\eta)^{-1} = -(b_1 + 2b_2\eta)^{-1}$, and the coordinates $Y(\eta)$ and $Z(\eta)$ of the centroidal axis are given by

$$Y(\eta) = Y_i + \int_0^{\eta} \cos[\phi(\eta) + \alpha] \, d\eta \qquad \text{(A.6a)}$$

and

$$Z(\eta) = Z_i + \int_0^{\eta} \sin[\phi(\eta) + \alpha] \, d\eta \qquad \text{(A.6b)}$$

where

$$\alpha = \tan^{-1}\left(\frac{Z_{i+1} - Z_i}{Y_{i+1} - Y_i}\right)$$

The thickness variation of each layer is approximated as being linear between nodes; thus

$$h_\ell = h_{i,\ell}\left(1 - \frac{\eta}{\eta_i}\right) + h_{i+1,\ell} \frac{\eta}{\eta_i} \qquad \text{(A.7)}$$

where subscript ℓ is used to denote quantities pertaining to the ℓth layer.

Employing the Bernoulli-Euler hypothesis, the displacement field $\tilde{v}$, $\tilde{w}$ of the beam may be specified by the reference plane displacements v and w,

and the rotation, ψ, as follows:

$$\tilde{v}(\eta,\zeta) = v(\eta) - \zeta\,\psi(\eta)$$
$$\tilde{w}(\eta,\zeta) = w(\eta) \tag{A.8}$$

where

$$\psi(\eta) = \frac{\partial w}{\partial \eta} - \frac{v}{R} \tag{A.8a}$$

To account for the strain-inducing modes and the rigid-body modes, the assumed displacement field takes the form:

$$\begin{Bmatrix} v \\ w \end{Bmatrix} = \begin{bmatrix} \cos\phi & \sin\phi & -(Z-Z_i)\cos(\phi+\alpha)+(Y-Y_i)\sin(\phi+\alpha) & \eta & 0 & 0 & \eta^2 & \eta^3 \\ -\sin\phi & \cos\phi & (Z-Z_i)\sin(\phi+\alpha)+(Y-Y_i)\cos(\phi+\alpha) & 0 & \eta^2 & \eta^3 & 0 & 0 \end{bmatrix} \begin{Bmatrix} \beta_1 \\ \vdots \\ \beta_8 \end{Bmatrix} \tag{A.9}$$

or in more compact matrix form, Eq. A.9 becomes

$$\{u\} \equiv \begin{Bmatrix} v \\ w \end{Bmatrix} = \begin{bmatrix} G_v(\eta) \\ G_w(\eta) \end{bmatrix} \{\beta\} \equiv \left[U(\eta)\right]\{\beta\} \tag{A.9a}$$

The generalized displacements {q} are selected so that there are four degrees of freedom v, w, ψ, $\chi = (\partial v/\partial \eta) + w/R$ at each node of the element:

$$\{q\} = \lfloor v_i \;\; w_i \;\; \psi_i \;\; \chi_i \;\; v_{i+1} \;\; w_{i+1} \;\; \psi_{i+1} \;\; \chi_{i+1} \rfloor^T = [A]\{\beta\} \tag{A.10}$$

where

$$[A] = \begin{bmatrix} \cos\phi_i & \sin\phi_i & 0 & 0 & 0 & 0 & 0 & 0 \\ -\sin\phi_i & \cos\phi_i & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ \cos\phi_{i+1} & \sin\phi_{i+1} & A_{53} & \eta_i & 0 & 0 & \eta_i^2 & \eta_i^3 \\ -\sin\phi_{i+1} & \cos\phi_{i+1} & A_{63} & 0 & \eta_i^2 & \eta_i^3 & 0 & 0 \\ 0 & 0 & 1 & \eta_i(\phi')_{\eta_i} & 2\eta_i & 3\eta_i^2 & \eta_i^2(\phi')_{\eta_i} & \eta_i^3(\phi')_{\eta_i} \\ 0 & 0 & 0 & 1 & -\eta_i^2(\phi')_{\eta_i} & -\eta_i^3(\phi')_{\eta_i} & 2\eta_i & 3\eta_i^2 \end{bmatrix} \tag{A.10a}$$

and

$$A_{53} = (Y_{i+1} - Y_i)\sin(\phi_{i+1} + \alpha) - (Z_{i+1} - Z_i)\cos(\phi_{i+1} + \alpha)$$

$$A_{63} = (Y_{i+1} - Y_i)\cos(\phi_{i+1} + \alpha) + (Z_{i+1} - Z_i)\sin(\phi_{i+1} + \alpha) \tag{A.10b}$$

Corresponding to the assumed displacement field Eq. A.9, one finds

$$\psi = \lfloor 0 \;\; 0 \;\; 1 \;\; -\frac{\eta}{R} \;\; 2\eta \;\; 3\eta^2 \;\; -\frac{\eta^2}{R} \;\; -\frac{\eta^3}{R} \rfloor \{\beta\} \equiv \lfloor G_\psi \rfloor \{\beta\} \tag{A.11a}$$

and

$$\chi = \lfloor 0 \;\; 0 \;\; 0 \;\; 1 \;\; \frac{\eta^2}{R} \;\; \frac{\eta^3}{R} \;\; 2\eta \;\; 3\eta^2 \rfloor \{\beta\} \equiv \lfloor G_\chi \rfloor \{\beta\} \tag{A.11b}$$

Under the Bernoulli-Euler hypothesis, the only nonvanishing strain component and corresponding stress component are the axial strain, $\tilde{\varepsilon}$, and axial stress, σ. For this case, the nonlinear strain-displacement relation may be expressed as:

$$\tilde{\varepsilon}(\eta,\zeta) = \varepsilon(\eta) + \zeta K(\eta) \tag{A.12}$$

where

$$\begin{aligned} \varepsilon(\eta) &= \left(\frac{\partial v}{\partial \eta} + \frac{w}{R}\right) + \frac{1}{2}\left(\frac{\partial v}{\partial \eta} + \frac{w}{R}\right)^2 + \frac{1}{2}\left(\frac{\partial w}{\partial \eta} - \frac{v}{R}\right)^2 \\ &\equiv \lfloor B_1 \rfloor \{u\} + \frac{1}{2}\lfloor u \rfloor \{B_1\} \lfloor B_1 \rfloor \{u\} + \frac{1}{2}\lfloor u \rfloor \{B_2\} \lfloor B_2 \rfloor \{u\} \end{aligned} \tag{A.12a}$$

$$K(\eta) = -\frac{\partial}{\partial \eta}\left(\frac{\partial w}{\partial \eta} - \frac{v}{R}\right) \equiv \lfloor B_3 \rfloor \{u\}$$

Combining Eqs. A.9 through A.12, one obtains

$$\{u\} = [U(\eta)][A^{-1}]\{q\} \tag{A.13}$$

and

$$\begin{aligned} \varepsilon &= \lfloor D_1 \rfloor \{q\} + \frac{1}{2}\lfloor q \rfloor \{D_1\} \lfloor D_1 \rfloor \{q\} + \frac{1}{2}\lfloor q \rfloor \{D_2\} \lfloor D_2 \rfloor \{q\} \\ K &= \lfloor D_3 \rfloor \{q\} \end{aligned} \tag{A.14}$$

where

$$\lfloor D_i \rfloor = \lfloor B_i \rfloor [U][A^{-1}] \qquad \text{for } i = 1, 2, 3 \qquad \text{(A.14a)}$$

and

$$\begin{aligned}
\lfloor B_1 \rfloor [U] &= \lfloor 0 \quad 0 \quad 0 \quad 1 \quad -\eta^2\phi' \quad -\eta^3\phi' \quad 2\eta \quad 3\eta^2 \rfloor \\
\lfloor B_2 \rfloor [U] &= \lfloor 0 \quad 0 \quad 1 \quad \eta\phi' \quad 2\eta \quad 3\eta^2 \quad \eta^2\phi' \quad \eta^3\phi' \rfloor \\
\lfloor B_3 \rfloor [U] &= \lfloor 0 \quad 0 \quad 0 \quad -\phi'-\eta\phi'' \quad -2 \quad -6\eta \quad -2\eta\phi'-\eta^2\phi'' \quad -3\eta^2\phi'-\eta^3\phi'' \rfloor
\end{aligned} \qquad \text{(A.14b)}$$

In the process of solution, it is necessary to evaluate the strain increment $\Delta\tilde{\varepsilon}_m$ from time t_{m-1} to time t_m. Using Eqs. A.12 and A.14, one has

$$\Delta\tilde{\varepsilon}_m = \Delta\varepsilon_m + \zeta\,\Delta K_m \qquad \text{(A.15)}$$

where

$$\begin{aligned}
\Delta\varepsilon_m = {} & \lfloor D_1 \rfloor \{\Delta q\}_m + \lfloor q \rfloor_m \{D_1\} \lfloor D_1 \rfloor \{\Delta q\}_m + \lfloor q \rfloor_m \{D_2\} \lfloor D_2 \rfloor \{\Delta q\}_m \\
& - \tfrac{1}{2} \lfloor \Delta q \rfloor_m \{D_1\} \lfloor D_1 \rfloor \{\Delta q\}_m - \tfrac{1}{2} \lfloor \Delta q \rfloor_m \{D_2\} \lfloor D_2 \rfloor \{\Delta q\}_m
\end{aligned} \qquad \text{(A.15a)}$$

$$\Delta K_m = \lfloor D_3 \rfloor \{\Delta q\}_m$$

The consistent mass matrix of the ith discrete element may be obtained from the expression for the kinetic energy, T_i, as follows:

$$T_i = \frac{1}{2}\int_{V_i} \rho\,(\dot{\tilde{v}}^2 + \dot{\tilde{w}}^2)\,dV = \frac{1}{2}\int_{V_i} \rho\left[(\dot{v} - \zeta\dot{\psi})^2 + \dot{w}^2\right] dV \qquad \text{(A.16)}$$

where V_i is the volume of the ith discrete element. The integration extending over the whole multilayer beam element is now performed by a summation of the integrals extending over each individual layer. Thus, one has

$$T_i = \frac{1}{2}\int_0^{\eta_i} \lfloor \dot{v} \quad \dot{w} \quad \dot{\psi} \rfloor [B] \begin{Bmatrix} \dot{v} \\ \dot{w} \\ \dot{\psi} \end{Bmatrix} d\eta \qquad \text{(A.16a)}$$

where

$$[B] = \sum_{\ell=1}^{L} b \begin{bmatrix} \rho_\ell h_\ell(\eta) & 0 & -\rho_\ell h_\ell(\eta)\lambda_\ell(\eta) \\ 0 & \rho_\ell h_\ell(\eta) & 0 \\ -\rho_\ell h_\ell(\eta)\lambda_\ell(\eta) & 0 & \rho_\ell\left(\frac{h_\ell^3(\eta)}{12} + h_\ell(\eta)\lambda_\ell^2(\eta)\right) \end{bmatrix} \qquad \text{(A.16b)}$$

and b is the width of the ring, $h_\ell(\eta)$ is the thickness of the ℓth layer, $\lambda_\ell(\eta)$ is the η-dependent ζ-location of the centroidal axis of the ℓth layer, and ρ_ℓ is the mass per unit volume of the ℓth layer. All quantities pertaining to the ℓth layer are denoted with subscript ℓ, and the summation extends over the L number of layers. Equation A.16b applies for ζ/R negligible compared with unity.

With the assumption that the velocity field is of a form which is consistent with the displacement function, Eqs. A.9 and A.11, one has

$$\begin{Bmatrix} \dot{v} \\ \dot{w} \\ \dot{\psi} \end{Bmatrix} = \begin{bmatrix} U(\eta) \\ \cdots\cdots \\ G_\psi(\eta) \end{bmatrix} \{\dot{\beta}\} \equiv [N(\eta)]\{\dot{\beta}\} = [N(\eta)][A^{-1}]\{\dot{q}\} \qquad \text{(A.17)}$$

Substituting Eq. A.17 into Eq. A.16a, one has

$$T_i = \frac{1}{2} \lfloor \dot{q} \rfloor [A^{-1}]^T \int_0^{\eta_i} [N]^T [B][N] \, d\eta \, [A^{-1}]\{\dot{q}\} \qquad \text{(A.18)}$$

or

$$T_i = \frac{1}{2} \lfloor \dot{q} \rfloor [m] \{\dot{q}\} \qquad \text{(A.18a)}$$

where the consistent mass matrix [m] of the element is

$$[m] = [A^{-1}]^T \int_0^{\eta_i} [N]^T [B][N] \, d\eta \, [A^{-1}] \qquad \text{(A.18b)}$$

The equivalent generalized nodal forces which correspond to the externally-applied loading can be obtained from the variational statement of the work of the externally-applied loading, δW_i:

$$\delta W_i = \int_0^{\eta_i} \left[F_v(\eta,t)\,\delta v + F_w(\eta,t)\,\delta w \right] d\eta \qquad \text{(A.19)}$$

where the components F_v and F_w of the force vector $\bar{F}$ are given by

$$\bar{F}(\eta,t) = F_v(\eta,t)\,\bar{a} + F_w(\eta,t)\,\bar{n} \qquad \text{(A.19a)}$$
$$= g_v(\eta)\,f_v(t)\,\bar{a} + g_w(\eta)\,f_w(t)\,\bar{n}$$

The quantity $\bar{F}(\eta,t)$ is the externally-applied time-varying forcing function.

Substituting the assumed displacement function, Eqs. A.9 and A.10 into Eq. A.19, one has

$$\delta W_i = \lfloor \delta q \rfloor [A^{-1}]^T \left\langle \int_0^{\eta_i} \{G_v(\eta)\}\, g_v(\eta)\, d\eta\, f_v(t) + \int_0^{\eta_i} \{G_w(\eta)\}\, g_w(\eta)\, d\eta\, f_w(t) \right\rangle \qquad \text{(A.20)}$$
$$\equiv \lfloor \delta q \rfloor \{f\}$$

where

$$\{f\} = [A^{-1}]^T \left\langle \int_0^{\eta_i} \{G_v\}\, g_v\, d\eta\, f_v + \int_0^{\eta_i} \{G_w\}\, g_w\, d\eta\, f_w \right\rangle$$
= element generalized nodal load vector (A.20a)

The effective stiffness matrix supplied by the elastic restraints may be obtained from the variation of the work done by the elastic restoring spring forces, δW_s:

$$-\delta W_s = \int_0^{\eta_i} (k_v\, v\, \delta v + k_w\, w\, \delta w + k_\psi\, \psi\, \delta\psi)\, d\eta \qquad \text{(A.21)}$$

or

$$-\delta W_s = \int_0^{\eta_i} \lfloor \delta v \;\; \delta w \;\; \delta\psi \rfloor [C] \begin{Bmatrix} v \\ w \\ \psi \end{Bmatrix} d\eta \qquad \text{(A.21a)}$$

where

$$[C] = \begin{bmatrix} k_v & 0 & 0 \\ 0 & k_w & 0 \\ 0 & 0 & k_\psi \end{bmatrix} \qquad \text{(A.21b)}$$

and k_v and k_w, respectively, are the linear elastic spring constants and k_ψ is the torsional elastic spring constant.

Substituting the assumed displacement function into Eq. A.21, one has

$$-\delta W_s = \lfloor \delta q \rfloor [A^{-1}]^T \int_0^{\eta_i} [N]^T [C][N] d\eta [A^{-1}]\{q\}$$
$$\equiv \lfloor \delta q \rfloor [k_s] \{q\} \tag{A.22}$$

where

$$[k_s] = [A^{-1}]^T \int_0^{\eta_i} [N]^T [C][N] \, d\eta \, [A^{-1}] \tag{A.22a}$$

= effective element stiffness matrix supplied by the elastic restraint

The variation of the internal work δU_i of the axial stress, σ, may be expressed in terms of displacements and plastic strains, wherein the large deflection and plasticity effects are taken into account through the use of "effective generalized loadings"; thus

$$\delta U_i = \int_{V_i} \sigma \, \delta \tilde{\varepsilon} \, dV = \int_{V_i} E(\varepsilon + \zeta K - \tilde{\varepsilon}^p)(\delta\varepsilon + \zeta \, \delta K) \, dV \tag{A.23}$$

Employing the strain-displacement relations given by Eqs. A.12 and A.14, Eq. A.23 becomes

$$\delta U_i = \lfloor \delta q \rfloor \left([k]\{q\} - \{f_q^{NL}\} - \{f_p^{L}\} - \{f_p^{NL}\} \right) \tag{A.24}$$

where, assuming that ζ/R is negligible compared with unity:*

$$[k] = \int_0^{\eta_i} [D_1 \,\vdots\, D_3] \sum_{\ell=1}^{L} \begin{bmatrix} b E_\ell h_\ell(\eta) & +bE_\ell h_\ell(\eta)\lambda_\ell(\eta) \\ +bE_\ell h_\ell(\eta)\lambda_\ell(\eta) & bE_\ell\left(\frac{h_\ell^3(\eta)}{12} + h_\ell(\eta)\lambda_\ell^2(\eta)\right) \end{bmatrix} \begin{bmatrix} D_1 \\ \hdashline D_3 \end{bmatrix} d\eta \tag{A.24a}$$

*Otherwise, additional terms would be present.

$$
\begin{aligned}
\{f_q^{NL}\} = &-\int_0^{\eta_i} \{D_1\} \Big(\tfrac{1}{2}(\chi^2+\psi^2)\Big\langle \sum_{\ell=1}^{L} bE_\ell h_\ell(\eta)\Big\rangle + \chi\,\varepsilon \Big\langle \sum_{\ell=1}^{L} bE_\ell h_\ell(\eta)\Big\rangle \\
&\qquad + \chi\,\mathcal{K}\Big\langle \sum_{\ell=1}^{L} bE_\ell h_\ell(\eta)\,\lambda_\ell(\eta)\Big\rangle \Big)\, d\eta \\
&-\int_0^{\eta_i} \{D_2\} \Big(\psi\,\varepsilon \Big\langle \sum_{\ell=1}^{L} bE_\ell h_\ell(\eta)\Big\rangle + \psi\,\mathcal{K}\Big\langle \sum_{\ell=1}^{L} bE_\ell h_\ell(\eta)\lambda_\ell(\eta)\Big\rangle \Big)\, d\eta \\
&-\int_0^{\eta_i} \{D_3\} \Big(\tfrac{1}{2}(\chi^2+\psi^2)\Big\langle \sum_{\ell=1}^{L} bE_\ell h_\ell(\eta)\,\lambda_\ell(\eta)\Big\rangle \Big)\, d\eta
\end{aligned}
\tag{A.24b}
$$

$$
\begin{aligned}
\{f_p^{L}\} = &\int_0^{\eta_i} \{D_1\} \Big(\sum_{\ell=1}^{L} bE_\ell \int_{h_\ell} \tilde{\varepsilon}^p(\eta,\zeta)\, d\zeta \Big)\, d\eta \\
&+\int_0^{\eta_i} \{D_3\} \Big(\sum_{\ell=1}^{L} bE_\ell \int_{h_\ell} \zeta\,\tilde{\varepsilon}^p(\eta,\zeta)\, d\zeta \Big)\, d\eta
\end{aligned}
\tag{A.24c}
$$

$$
\begin{aligned}
\{f_p^{NL}\} = &\int_0^{\eta_i} \{D_1\} \Big(\chi \sum_{\ell=1}^{L} bE_\ell \int_{h_\ell} \tilde{\varepsilon}^p(\eta,\zeta)\, d\zeta \Big)\, d\eta \\
&+\int_0^{\eta_i} \{D_2\} \Big(\psi \sum_{\ell=1}^{L} bE_\ell \int_{h_\ell} \tilde{\varepsilon}^p(\eta,\zeta)\, d\zeta \Big)\, d\eta
\end{aligned}
\tag{A.24d}
$$

and in the above, E_ℓ is the modulus of elasticity of the ℓth layer, and $\tilde{\varepsilon}^p$ is the plastic strain.

Note that in the present analysis the integrations along the beam span are performed numerically by employing Gaussian quadrature which requires the integrand to be evaluated only at each selected spanwise Gaussian station. At

each spanwise station, the integration of the plastic strain, $\tilde{\varepsilon}^p$, through the thickness of each individual layer, also requires evaluating $\tilde{\varepsilon}^p$ at selected Gaussian points across the thickness of each layer and the corresponding weighting factors are used in evaluating the pertinent integrals by Gaussian quadrature; hence

$$\int_{h_\ell} \tilde{\varepsilon}^p d\zeta = \frac{h_\ell}{2} \sum_{j=1}^{J} \tilde{\varepsilon}_j^p W_j$$
$$\int_{h_\ell} \zeta \tilde{\varepsilon}^p d\zeta = \frac{h_\ell}{2} \sum_{j=1}^{J} \zeta_{j,\ell} \tilde{\varepsilon}_j^p W_j \tag{A.25}$$

where

$$\zeta_{j,\ell} = \frac{h_\ell}{2} \zeta_j' + \lambda_\ell$$
$$\tilde{\varepsilon}_j^p = \tilde{\varepsilon}^p(\zeta_{j,\ell}) \quad \text{and} \quad \int_{h_\ell} \equiv \int_{\lambda_\ell(\eta) - \frac{h_\ell(\eta)}{2}}^{\lambda_\ell + \frac{h_\ell}{2}} \tag{A.25a}$$

and J denotes the number of Gaussian points that have been used for the thickwise integration through the cross section of each beam layer; ζ_j' and W_j are the numerical values of the jth Gaussian station and weight, respectively.

Since the strain-hardening behavior of the material is accounted for by using the mechanical sublayer model in which the material at each Gaussian station is treated as consisting of equally-strained sublayers of elastic, perfectly-plastic material with each sublayer having the same elastic modulus but an appropriately different yield stress, the plastic strain at any station is calculated from the plastic strain of each mechanical-sublayer at that station. Let K mechanical-sublayers be used to approximate the strain-hardening material behavior. Thus, one has:

$$\int_{h_\ell} \tilde{\varepsilon}^p d\zeta = \frac{h_\ell}{2} \sum_{j=1}^{J} W_j \left(\sum_{k=1}^{K} \tilde{\varepsilon}_{jk}^p C_k \right)$$
$$\int_{h_\ell} \zeta \tilde{\varepsilon}^p d\zeta = \frac{h_\ell}{2} \sum_{j=1}^{J} \zeta_{j,\ell} W_j \left(\sum_{k=1}^{K} \tilde{\varepsilon}_{jk}^p C_k \right) \tag{A.26}$$

where C_k, the mechanical sublayer weighting factor, is defined by

$$C_k = \frac{1}{E} \left(E_k - E_{k+1} \right) \tag{A.26a}$$

$$E_k = \frac{\sigma_k - \sigma_{k-1}}{\varepsilon_k - \varepsilon_{k-1}} \tag{A.26b}$$

is the kth slope of the polygonal approximate stress-strain diagram. The quantities σ_k, ε_k represent the coordinate defining the piecewise-linear approximation of the uniaxial stress-strain curve.

An illustration of the method of computing the axial stress and plastic-strain increment of any mechanical sublayer of the material model at any spanwise or depthwise Gaussian station, is presented as follows. One begins by knowing the sublayer stress $(\sigma_{jk})_{m-1}$ at time t_{m-1} for the kth sublayer of the jth depthwise Gaussian station, and the strain increment $(\Delta\tilde{\varepsilon}_j)_m$ at station j at time t_m (that is, the strain increment from time t_{m-1} to time t_m). One then takes a trial value (superscript T) of $(\sigma_{jk})_m$ which is computed by assuming an elastic path:

$$(\sigma_{jk})_m^T = (\sigma_{jk})_{m-1} + E(\Delta\tilde{\varepsilon}_j)_m \tag{A.27}$$

A check is then performed to see what the correct value of $(\sigma_{jk})_m$ must be:

$$\begin{aligned}
&\text{If } -\sigma_{ok} \le (\sigma_{jk})_m^T \le \sigma_{ok} \quad \text{then } (\sigma_{jk})_m = (\sigma_{jk})_m^T \quad \text{and } (\Delta\varepsilon_{jk}^p)_m = 0 \\
&\text{If } (\sigma_{jk})_m^T > \sigma_{ok} \quad \text{then } (\sigma_{jk})_m = \sigma_{ok} \quad \text{and } (\Delta\varepsilon_{jk}^p)_m = \frac{(\sigma_{jk})^T - \sigma_{ok}}{E} \\
&\text{If } (\sigma_{jk})_m^T < -\sigma_{ok} \quad \text{then } (\sigma_{jk})_m = -\sigma_{ok} \quad \text{and } (\Delta\varepsilon_{jk}^p)_m = \frac{(\sigma_{jk})^T + \sigma_{ok}}{E}
\end{aligned} \tag{A.28}$$

If desired, the sublayer yield stresses may be treated as strain-rate dependent. Since the strain increment at the jth Gaussian station and hence the strain rate is known at this stage of computation, then the rate-dependent yield stress σ_{yk} of this kth sublayer at station j is

$$\sigma_{yk} = \sigma_{ok}\left(1 + \left|\frac{\Delta\tilde{\varepsilon}/\Delta t}{D}\right|^{\frac{1}{p}}\right) \tag{A.29}$$

where D and p are empirically-determined constants* for the material and may, in general, be different for each sublayer, σ_{ok} is the static uniaxial yield stress of the kth sublayer at any jth Gaussian station and is defined by $\sigma_{ok} = E\,\varepsilon_k$.

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*See the footnote on page 39.

Finally, by employing the standard finite-element assembling procedure, the resulting equations of motion for the "complete discretized structure" are

$$[\overset{*}{M}]\{\ddot{q}^*\} + ([\overset{*}{K}] + [\overset{*}{K_s}])\{q^*\} = \{\overset{*}{F}\} + \{\overset{*}{F}{}_q^{NL}\} + \{\overset{*}{F}{}_p^{L}\} + \{\overset{*}{F}{}_p^{NL}\} \tag{A.30}$$

where the nomenclature of each term is explained in Subsection 2.3.

A.2 Solution Procedure for JET 5A

The Houbolt operator is a 4-point backward difference implicit operator and is chosen to solve the equations of motion expressed in the conventional form, Eq. 2.2. In this solution scheme, the $\{\ddot{q}^*\}$ at any instant of time t_{m+1} are approximated by a 4-point backward-difference expression:

$$\{\ddot{q}^*\}_{m+1} = \frac{2\{q^*\}_{m+1} - 5\{q^*\}_m + 4\{q^*\}_{m-1} - \{q^*\}_{m-2}}{(\Delta t)^2} + O(\Delta t)^2 \tag{A.31}$$

Employing Eq. A.31, the conventional form of the dynamic equations of equilibrium, Eq. A.30, becomes

$$\left\langle 2[M^*] + (\Delta t)^2([K^*] + [K_s^*])\right\rangle \{q^*\}_{m+1} = (\Delta t)^2 \left\langle \{\overset{*}{F}\}_{m+1} + \{\overset{*}{F}{}_q^{NL}\}_{m+1} + \{\overset{*}{F}{}_p^{L}\}_{m+1} + \{\overset{*}{F}{}_p^{NL}\}_{m+1}\right\rangle$$
$$+ [M^*]\left(5\{q^*\}_m - 4\{q^*\}_{m-1} + \{q^*\}_{m-2}\right) \tag{A.32}$$

It should be noted that the generalized nodal load vectors $\{\overset{*}{F}{}_q^{NL}\}_{m+1}$, $\{\overset{*}{F}{}_p^{L}\}_{m+1}$ and $\{\overset{*}{F}{}_p^{NL}\}_{m+1}$ (which may be due to large-deflections and elastic-plastic effects) depend on the displacements (or stresses, strains) at the time instant t_{m+1}, but these remain to be determined; thus, linear extrapolation by using the generalized nodal load vectors at two previous time steps is employed to estimate these forces values:

$$\left\{\overset{*}{F}{}_q^{NL}\right\}_{m+1}+\left\{\overset{*}{F}{}_p^{L}\right\}_{m+1}+\left\{\overset{*}{F}{}_p^{NL}\right\}_{m+1} \doteq 2\left(\left\{\overset{*}{F}{}_q^{NL}\right\}_m+\left\{\overset{*}{F}{}_p^{L}\right\}_m+\left\{\overset{*}{F}{}_p^{NL}\right\}_m\right)$$
$$-\left(\left\{\overset{*}{F}{}_q^{NL}\right\}_{m-1}+\left\{\overset{*}{F}{}_p^{L}\right\}_{m-1}+\left\{\overset{*}{F}{}_p^{NL}\right\}_{m-1}\right) \qquad \text{(A.33)}$$

This estimation should be reasonably good for very small Δt but will deteriorate with increasing Δt.

In order to apply the calculation method represented by Eqs. A.32 and A.33, one must take into account the prescribed initial conditions, $\{q^*\}_o$, $\{\dot{q}^*\}_o$, and $\{F^*\}_o$. The following "starting procedure" for this method provides the generalized displacements $\{q^*\}_1$ at $t_1 = 1\Delta t$, and $\{q^*\}_{-1}$ at a negative (fictitious) time instant $t_{-1} = - 1\Delta t$.

By employing the following approximations:

$$\left\{\dot{q}^*\right\}_o = \frac{2\{q^*\}_1 + 3\{q^*\}_o - 6\{q^*\}_{-1} + \{q^*\}_{-2}}{6(\Delta t)} \qquad \text{(A.34)}$$

and

$$\left\{\ddot{q}^*\right\}_o = \frac{\{q^*\}_1 - 2\{q^*\}_o + \{q^*\}_{-1}}{(\Delta t)^2} + O(\Delta t)^2 \qquad \text{(A.35)}$$

one has

$$\left\{q^*\right\}_{-1} = (\Delta t)^2\{\ddot{q}^*\}_o + 2\{q^*\}_o - \{q^*\}_1 \qquad \text{(A.36)}$$

$$\left\{q^*\right\}_{-2} = 6(\Delta t)^2\{\ddot{q}^*\}_o + 6(\Delta t)\{\dot{q}^*\}_o + 9\{q^*\}_o - 8\{q^*\}_1 \qquad \text{(A.37)}$$

Substituting Eqs. A.36 and A.37 into Eq. A.32 for m = 0 and approximating the generalized nodal load vectors due to large-deflections and elastic-plastic effects at time step t_1 by their values at time zero, one obtains

$$\left\langle 6[M^*]+(\Delta t)^2\left([K^*]+[K_s^*]\right)\right\rangle\{q^*\}_1 = (\Delta t)^2\left(\{F^*\}_1+\left\{\overset{*}{F}{}_q^{NL}\right\}_o+\left\{\overset{*}{F}{}_p^{L}\right\}_o+\left\{\overset{*}{F}{}_p^{NL}\right\}_o\right)$$
$$+[M^*]\left(2(\Delta t)^2\{\ddot{q}^*\}_o + 6(\Delta t)\{\dot{q}^*\}_o + 6\{q^*\}_o\right) \qquad \text{(A.38)}$$

where $\{\ddot{q}^*\}_o$ can be calculated from

$$[M^*]\{\ddot{q}^*\}_o = \{F^*\}_o - \left([K^*] + [K_s^*]\right)\{q^*\}_o + \left(\{\bar{F}_q^{*NL}\}_o + \{\bar{F}_p^{*L}\}_o + \{\bar{F}_p^{*NL}\}_o\right) \tag{A.39}$$

Since the right-hand side of Eq. A.38 is known, one can solve for $\{q^*\}_1$. After the $\{q^*\}_1$ have been determined, $\{q^*\}_{-1}$ can be computed from Eq. A.36. One can then proceed to calculate $\{q^*\}_2$ from Eqs. A.32 and A.33, then $\{q^*\}_3$, $\{q^*\}_4$, etc.

APPENDIX B

GOVERNING EQUATIONS ON WHICH CIVM-JET 5B IS BASED

The governing equations for CIVM-JET 5B are similar to those discussed for JET 5A in Appendix A, except that (1) prescribed initial velocities and/or prescribed externally-applied forces acting on the containment/deflector ring structure are not accommodated, (2) a diagonal lumped rather than a consistent mass matrix is used, and (3) ring/fragment impact and interaction must now be taken into account. The new matters pertinent to CIVM-JET 5B are discussed in the following subsections, whose headings identify the principal subject matter.

At this point it is useful to recall the general flow of information and computations in CIVM-JET 5B as depicted in Fig. 9. The key aspects of that process are discussed in the following subsections.

B.1 Equations of Motion of the C/D Ring Structure

The equations of motion for the finite-element representation of the containment/deflector (C/D) ring structure are represented by Eq. A.30 except that now $\{F^*\} = 0$ and a diagonal lumped mass matrix is to be used; all other formulation and discussion in Appendix A prior to Eq. A.30 also apply to CIVM-JET 5B.

The rationale for employing a diagonal lumped-mass representation for the C/D ring structure which is to be subjected to fragment-impact attack has been discussed in Subsection 2.3, page 11. For the present multilayer, multi-material curved-ring element, a diagonal lumped-mass matrix is constructed from the consistent mass matrix ($\underset{\sim}{m}^c$, Eq. A.18b) according to the following rules (chosen for their convenience):

$$
\begin{aligned}
(m_{11})_L &= m_{11}^c + m_{15}^c \\
(m_{22})_L &= m_{22}^c + m_{26}^c \\
(m_{33})_L &= m_{33}^c \quad ; \quad (m_{44})_L = m_{44}^c
\end{aligned}
\tag{B.1}
$$

$$(m_{55})_L = m^c_{55} + m^c_{51}$$

$$(m_{66})_L = m^c_{66} + m^c_{61}$$

$$(m_{77})_L = m^c_{77} \quad ; \; (m_{88})_L = m^c_{88}$$

This insures that $(m_{11})_L + (m_{55})_L = (m_{22})_L + (m_{66})_L$ = the total mass of the element; these quantities pertain to the "translational degrees of freedom v_i, w_i, v_{i+1}, and w_{i+1}. The remaining terms refer to the degrees of freedom ψ_i, χ_i, ψ_{i+1}, and χ_{i+1}. Exploratory calculations indicate that the predicted structural response of an impulsively-loaded structure (a simple beam, for example) is rather insensitive to the type of mass lumping applied* to these degrees of freedom and compares well with that obtained by using the consistent mass matrix. It turns out also that the Eq. B.1 mass lumping produces a (perhaps advantageous) smaller ω_{max} than does the consistent mass or the footnote-cited (*) diagonal mass lumping.

B.2 Collision-Interaction Analysis, Including Friction

In the present collision-interaction analysis, the curved variable-thickness multilayer containment/deflection ring is represented by straight-line segments (Fig. B.1): (a) to identify in a simple and approximate way the space occupancy of the beam segment under imminent impact attack and (b) to derive the impact equations. The inertia effects of the impacted beam segments are taken into account by means of lumped-mass collision model; that is, the ring is treated as having only point masses lumped at each nodal station as indicated in Fig. B.2. Other simplifying assumptions which are invoked in the present analysis are described in Subsection 2.2.

*That is the lumping given by Eq. B.1 wherein $(m_{33})_L$, $(m_{44})_L$, $(m_{77})_L$, and $(m_{88})_L$ are computed in a fashion analogous to that indicated in Eq. B.1 for $(m_{11})_L$, $(m_{22})_L$, $(m_{55})_L$, and $(m_{66})_L$.

For the lumped-mass collision model, the impact-affected beam segments are represented, as depicted in the exploded-line schematic of Fig. B.2, by concentrated masses m_1, m_2, ..., m_{j+1}, ..., m_k (or i+k-1), respectively, where the ring-fragment collision point is encompassed by the jth segment which is bounded by nodal station j and j+1 ---- a clockwise numbering sequence is used. In the collision analysis, it is convenient to resolve and discuss impulses, velocities, etc., for both of the fragment and the ring impact-affected nodes in directions normal (N) and tangential (T) to the straight line segment j; the positive normal direction is always taken from the inside toward the outside of the ring, while the positive-tangential direction is along the straight line from node j toward node j+1 (see Fig. B.2a). Consequently, the lumped-mass velocities for each of the impact-affected nodes and the idealized-fragment velocities are expressed with respect to this local N,T inertial coordinate system as (V_{IN}, V_{IT}), (V_{2M}, V_{2T}) ---- (V_{kN}, V_{kT}), and (V_{fN}, V_{fT}) in the exploded schematic shown in Fig. B.2a.

It is assumed that the instantaneous collision process results in a normal-direction impulse $\tilde{p}_N$ and a tangentially directed impulse $\tilde{p}_T$ applied to the ring, and in equal but anti-parallel impulses to the fragment. The impulses applied to the ring are assumed to be distributed over the impact-affected nodes (see Fig. B.2b) as

$$\left.\begin{aligned} p_{iN} &= C\left(1 - \frac{|s_i|}{L_{eff}}\right)\tilde{p}_N \equiv C\,\alpha_i'\,\tilde{p}_N \\ p_{iT} &= C\left(1 - \frac{|s_i|}{L_{eff}}\right)\tilde{p}_T \equiv C\,\alpha_i'\,\tilde{p}_T \end{aligned}\right\}\ i = 1, 2, \ldots, k \qquad \text{(B.2)}$$

where (see Fig. B.2b) the effective length*, L_{eff}, bounds the impact-affected zone of the ring, which is the fraction of the ring that responds with momentum changes due to the collision of a fragment, s_i is the distance measured from the impacted point to the ith impact-affected node, and the constant, C, is determined by assuming that the sum of the impulse applied to each impact-affected node equals the total impulse imparted; thus,

---

* One estimate for L_{eff} (called EFLN in the program) is $L_{eff} \doteq \Delta t(E/\rho)^{1/2}$ where Δt is the finite-difference-calculation time increment and $(E/\rho)^{1/2}$ is the largest longitudinal rod wave speed of the layers in the layered structure; E is the elastic modulus and ρ is the mass per unit volume. Another estimate from through-the-thickness stress wave propagation considerations is $L_{eff} \doteq nh$ where h is the total thickness of the layered structure and n is some number, typically like $2 \lesssim n \lesssim 4$.

$$\sum_{i=1}^{k} p_{iN} = \tilde{p}_N \quad \left(\text{or} \sum_{i=1}^{k} p_{iT} = \tilde{p}_T\right) \tag{B.2a}$$

Therefore, one has

$$C = 1 \Big/ \sum_{i=1}^{k} \left(1 - \frac{|s_i|}{L_{eff}}\right) \equiv 1 \Big/ \sum_{i=1}^{k} \alpha_i' \tag{B.2b}$$

The impact-affected nodes are those nodes located within the impact affected zone; that is $|s_i|<L_{eff}$. However, it is assumed that the two-mass nodes j and j+1 of the segment j which encompasses the impact point <u>always</u> respond to impact with momentum changes, even if the distance from the impact point to one or both of the two nodes (j and j+1) is greater than L_{eff}. Let β and γ be the distances measured from the "point of fragment impact" to masses m_j and m_{j+1}, respectively, as indicated in Fig. B.2. The distribution of the impulses is estimated in the following manner:

(1) If $\beta \geq L_{eff}$ and $\gamma < L_{eff}$, then (Fig. B.2c):

$$p_{1N} = p_{jN} = C\alpha_1' \tilde{p}_N \tag{B.3}$$
$$p_{1T} = p_{jT} = C\alpha_1' \tilde{p}_T$$

where

$$\alpha_1' = \frac{\gamma}{\beta}\alpha_2' \quad \text{and} \quad C = 1 \Big/ \sum_{i=1}^{k} \alpha_i' \tag{B.3a}$$

(2) If $\beta < L_{eff}$ and $\gamma \geq L_{eff}$, then (Fig. B.2d):

$$p_{kN} = p_{(j+1)N} = C\alpha_k' \tilde{p}_N \tag{B.4}$$
$$p_{kT} = p_{(j+1)N} = C\alpha_k' \tilde{p}_T$$

where

$$\alpha_k' = \frac{\beta}{\gamma}\alpha_{k-1}' \quad \text{and} \quad C = 1 \Big/ \sum_{i=1}^{k} \alpha_i' \tag{B.4a}$$

(3) If $\beta \geq L_{eff}$ and $\gamma \geq L_{eff}$, then (Fig. B.2e)

$$p_{1N} = p_{jN} = C\gamma\tilde{p}_N \equiv C\alpha_1'\tilde{p}_N \tag{B.5a}$$
$$p_{2N} = p_{(j+1)N} = C\beta\tilde{p}_N \equiv C\alpha_2'\tilde{p}_N$$

$$p_{1T} = p_{jT} = C\gamma\tilde{p}_T \equiv C\alpha_1'\tilde{p}_T \tag{B.5b}$$
$$p_{2T} = p_{(j+1)T} = C\beta\tilde{p}_T \equiv C\alpha_2'\tilde{p}_T$$

where

$$C = 1/(\beta+\gamma) \tag{B.5c}$$

It should be emphasized here that the determination of which mass nodes fall within the impact-affected region is a discrete process in the sense that only mass node locations are considered instead of considering the true volume of mass included in the impact-affected region of the structure. Such an approximation is made necessary by the use of a lumped-mass model in the collision-interaction analysis. In essence, the use of a lumped-mass model implies that the nodal mass represents the mass distribution in a region of the structure surrounding the node, and, thus, by including a mass node in the impact-affected region, one is automatically including, in the impact-affected region, that portion of mass in the region of the node. It is clear that, in general, this approximate technique will result in having more or less structural mass included in the impact-affected region compared with the true structural mass within L_{eff}. However, in an average sense, this discrepancy is within the overall approximate nature of the impact-interaction analysis. In addition, the calculation of L_{eff}, which defines the distance the collision-imparted impulse "signal" travels in the structure during a finite time interval, is based on the global increment in time, Δt. This implies that the collision occurs at the beginning of a time step, and that the "signal" travels for a length of time equal to Δt. In actuality the time of impact may occur at any moment within a Δt. However, as detailed in Subsection B.5, the impact interaction solution assumes that all impacts occur at the beginning of a time step. This approximation of L_{eff} counterbalances the discrete process of determining which mass nodes fall within the impact-affected region. It is believed that these calculations, although approximate, will yield reasonable results for the fragment-impact-induced structural response.

Denoting by primes the "after-impact" translational and/or rotational velocities, the impulse-momentum law may be written to characterize the "instantaneous impact behavior" of the system, as follows:

Normal-Direction Translation Impulse-Momentum Law

$$m_f\left[V'_{fN} - V_{fN}\right] = -\tilde{p}_N \qquad \text{(fragment)} \qquad (B.6)$$

$$\left.\begin{aligned} m_1\left[V'_{1N} - V_{1N}\right] &= \alpha_1 \tilde{p}_N \\ m_2\left[V'_{2N} - V_{2N}\right] &= \alpha_2 \tilde{p}_N \\ &\vdots \\ m_k\left[V'_{kN} - V_{kN}\right] &= \alpha_k \tilde{p}_N \end{aligned}\right\} \qquad \text{(ring impact-affected nodes)} \qquad (B.7)$$

Tangential-Direction Translational Impulse-Momentum Law

$$m_f\left[V'_{fT} - V_{fT}\right] = -\tilde{p}_T \qquad \text{(fragment)} \qquad (B.8)$$

$$\left.\begin{aligned} m_1\left[V'_{1T} - V_{1T}\right] &= \alpha_1 \tilde{p}_T \\ m_2\left[V'_{2T} - V_{2T}\right] &= \alpha_2 \tilde{p}_T \\ &\vdots \\ m_k\left[V'_{kT} - V_{kT}\right] &= \alpha_k \tilde{p}_T \end{aligned}\right\} \qquad \text{(ring impact-affected nodes)} \qquad (B.9)$$

Rotational Impulse-Momentum Law

$$I_f\left[\omega'_f - \omega_f\right] = r_f\,\tilde{p}_T \qquad \text{(fragment)} \qquad (B.10)$$

where

m_f = mass of the fragment

I_f = mass moment of inertia of the fragment about its CG

r_f = the radius of the circular disk model of the fragment

$\tilde{p}_N$ = normal-direction impulse

$\tilde{p}_T$ = tangential-direction impulse

α_i = proportional constant which is equal to $(C\alpha'_i)$ as defined by Eqs. B.2 through B.5c.

The relative velocity of sliding S' and the relative velocity of approach A' at the immediate "contact points" between the fragment (at C_f) and the ring

segment j (at C_r) are defined by

$$S' = [V'_{fT} - \omega'_f r_f] - [\alpha_1 V'_{1T} + \alpha_2 V'_{2T} + \ldots + \alpha_k V'_{kT}] \tag{B.11}$$

$$A' = V'_{fN} - [\alpha_1 V'_{1N} + \alpha_2 V'_{2N} + \ldots + \alpha_k V'_{kN}] \tag{B.12}$$

Substituting Eqs. B.6 through B.10 into Eqs. B.11 and B.12, one obtains

$$S' = S_o - B_1 \tilde{p}_T \tag{B.13}$$

$$A' = A_o - B_2 \tilde{p}_N \tag{B.14}$$

where the initial (pre-impact) relative velocity of sliding S_o, the initial relative velocity of approach A_o, and the geometrical constants B_1 and B_2 are given by

$$S_o = [V_{fT} - \omega_f r_f] - [\alpha_1 V_{1T} + \alpha_2 V_{2T} + \ldots + \alpha_k V_{kT}] \tag{B.15}$$

$$A_o = V_{fN} - [\alpha_1 V_{1N} + \alpha_2 V_{2N} + \ldots + \alpha_k V_{kN}] \tag{B.16}$$

$$B_1 = \frac{1}{m_f} + \frac{r_f^2}{I_f} + \frac{\alpha_1^2}{m_1} + \frac{\alpha_2^2}{m_2} + \ldots + \frac{\alpha_k^2}{m_k} \tag{B.17}$$

$$B_2 = \frac{1}{m_f} + \frac{\alpha_1^2}{m_1} + \frac{\alpha_2^2}{m_2} + \ldots + \frac{\alpha_k^2}{m_k} \tag{B.18}$$

where in Eqs. B.15 and B.16 by definition $A_o \geq 0$; otherwise, the two bodies will not collide with each other. Also, if $S_o \geq 0$, the fragment slides initially along the ring segment. It perhaps should be noted that sliding of the bodies on each other is assumed to occur at the value of "limiting friction" which requires that $p_T = |\mu p_N|$, and when $p_T < |\mu p_N|$, only rolling (i.e., no sliding) exists. For a given value of e and a given value of μ which, respectively, describes the degree of "plasticity" of the collision process, and accounts for the frictional properties (roughness) of the contact surfaces+, 2(k+1)+3 equations (Eqs. B.6 - B.10 and Eqs. B.13 - B.14) can be solved to obtain the post-impact quantities (V'_{1N}, V'_{1T}), (V'_{2N}, V'_{2T}), ..., (V'_{kN}, V'_{kT}), (V'_{fN}, V'_{fT}) and ω'_f as well as $\tilde{p}_N$ and $\tilde{p}_T$; these are the 2 (k+1) +3 "unknowns".

+For μ and e effects, see pages 335 and 336.

The graphic technique which provides a convenient way to obtain the values of $\tilde{p}_N$ and $\tilde{p}_T$ at the instant of the termination of impact as described in Ref. 5 is employed in the present collision-interaction analysis. In this technique, the trajectory of an "image" point $\overline{P}$ in the plane formed by the impulse coordinates $\tilde{p}_N$ and $\tilde{p}_T$ (Fig. B.3) represents the state of the colliding bodies at each instant of the contact interval. The image point $\overline{P}$ which is initially located at the origin and is denoted by $\tilde{p}_o$ ($\tilde{p}_N = 0$, $\tilde{p}_T = 0$) will always proceed in the upper half-plane with increasing $\tilde{p}_N$. The locations of the line of no sliding $S' = 0$ and the line of maximum approach $A' = 0$ are determined by the system constants B_1 and B_2. From Eqs. B.13 through B.18, it is noted that B_1 and B_2 are positive always; also the lines $S' = 0$ and $A' = 0$ are parallel to the $\tilde{p}_N$ axis and the $\tilde{p}_T$ axis, respectively, and intersect with each other at point P_3 in the first quadrant of the $\tilde{p}_N$, $\tilde{p}_T$ plane as shown in Fig. B.3. Depending on the values of the coefficient of sliding friction μ, the coefficient of restitution e, the system constants B_1 and B_2, and the initial conditions S_o and A_o, several variations of the impact process may occur and will be discussed in the following.

First, the cases in which the coefficient of sliding friction μ ranges from $0<\mu<\infty$ will be considered; the two special cases with $\mu = 0$ (perfectly-smooth contact surfaces) and $\mu = \infty$ (completely rough surfaces) will be discussed shortly thereafter.

<u>Case I:</u> If $0<\mu<\infty$, the friction angle ν and the angle Λ formed with the $\tilde{p}_N$ axis by the line connecting P_o and P_3 are defined by

$$\nu = \tan^{-1}\mu \tag{B.19}$$

and

$$\Lambda = \tan^{-1}\left(\frac{B_2 S_o}{B_1 A_o}\right) \tag{B.20}$$

Initially, the image point $\overline{P}$ travels from point P_o along the path P_oL which subtends an angle ν with the P_N axis because the limiting friction impulse $p_T = \mu p_N$ is developed during the initial stage of impact. Subsequently:

(a) if $\mu = \tan\nu < \tan\Lambda$ (Fig. B.3a), line P_oL will intersect the line of maximum approach $A' = 0$ at point P_1, before reaching the line of no sliding $S' = 0$. The intersection

point P_1 represents the state at the instant of the termination of the approach period. This is followed by the restitution period; the impact process ceases at point P' (path $P_o - P_1 - P'$). The coordinates of P' are+

$$\tilde{p}_N = (1+e)\, p_{N1} \tag{B.21}$$

$$\tilde{p}_T = \mu \tilde{p}_N = \mu(1+e)\, p_{N1} \tag{B.22}$$

where p_{N1}, the ordinate of point P_1 is determined from the simultaneous solution of equations $p_T = \mu p_N$ and $A' = 0$, and is given by

$$p_{N1} = \frac{A_o}{B_2} \tag{B.23}$$

(b) However, if $\mu = \tan \nu \geq \tan \Lambda$ (Fig. B.3b), line P_oL will intersect the line of no sliding $S' = 0$ first at the intersection point P_2 which marks the end of the initial sliding phase. The image point $\overline{P}$ then will continue to proceed along the line of no sliding $S' = 0$ through the intersection point P_3 with line $A' = 0$ to the end of impact at point P' (path $P_o - P_2 - P_3 - P'$). The final values of $\tilde{p}_N$ and $\tilde{p}_T$ are:

$$\tilde{p}_N = (1+e)\, p_{N3} \tag{B.24}$$

$$\tilde{p}_T = \frac{S_o}{B_1} \tag{B.25}$$

where p_{N3} is the ordinate of point P_3 which represents the end of the approach period and is given by

$$p_{N3} = \frac{A_o}{B_2} \tag{B.26}$$

The above solution process can be specialized to represent the cases with $\mu = 0$ and $\mu = \infty$.

Case II: If $\mu = 0$ (perfectly smooth contact surfaces), line P_oL coalesces with the p_N axis. The image point $\overline{P}$ will move along the p_N axis to the end of

+Coefficient of restitution e: perfectly elastic $e = 1$; perfectly plastic $e = 0$; and intermediate $0<e<1$.

impact. Thus

$$\tilde{p}_N = (1+e)\frac{A_o}{B_2} \tag{B.27}$$

$$\tilde{p}_T = 0 \tag{B.28}$$

Case III: If $\mu = \infty$ (completely rough contact surface), point $\bar{P}$ moves initially along the P_T axis to the intersection with $S' = 0$, then will follow the line $S' = 0$ to the end of impact. The post impact value of $\tilde{p}_N$ and $\tilde{p}_T$ are

$$\tilde{p}_N = (1+e)\frac{A_o}{B_2} \tag{B.29}$$

$$\tilde{p}_T = \frac{S_o}{B_1} \tag{B.30}$$

Knowing the values of $\tilde{p}_N$ and $\tilde{p}_T$ at the end of impact for the above discussed various impact processes, the corresponding post-impact velocities then can be determined from Eqs. B.6 through B.10 as follows:

$$\left.\begin{aligned} V_{1N}' &= V_{1N} + \frac{\alpha_1 \tilde{p}_N}{m_1} \\ V_{1T}' &= V_{1T} + \frac{\alpha_1 \tilde{p}_T}{m_1} \end{aligned}\right\} \quad \text{Node 1} \tag{B.31}$$

$$\left.\begin{aligned} V_{2N}' &= V_{2N} + \frac{\alpha_2 \tilde{p}_N}{m_2} \\ V_{2T}' &= V_{2T} + \frac{\alpha_2 \tilde{p}_T}{m_2} \end{aligned}\right\} \quad \text{Node 2} \tag{B.32}$$

$$\vdots$$

$$\left.\begin{aligned} V_{kN}' &= V_{kN} + \frac{\alpha_k \tilde{p}_N}{m_k} \\ V_{kT}' &= V_{kT} + \frac{\alpha_k \tilde{p}_T}{m_k} \end{aligned}\right\} \quad \text{Node k} \tag{B.33}$$

$$\left.\begin{aligned} V'_{fN} &= V_{fN} - \frac{\tilde{p}_N}{m_f} \\ V'_{fT} &= V_{fT} - \frac{\tilde{p}_T}{m_f} \\ \omega'_f &= \omega_f + \frac{r_f\ \tilde{p}_T}{I_f} \end{aligned}\right\} \text{ Fragment} \qquad \text{(B.34)}$$

Thus, this approximate analysis provides the post-impact velocity information for the impact-affected nodes of the ring and for the fragment so that the timewise step-by-step solution of this ring/fragment response problem may proceed. Note that these post-impact velocity components are given in directions N and T at each node of the idealized impact-affected ring segments; as explained later, these velocity components are then transformed to (different) directions appropriate for the curved-ring dynamic response analysis.

B.3 Prediction of Containment/Deflector Ring Motion and Position

The timewise solution of the resulting equations of motion for the "complete assembled discretized structure", Eq. A.30,+ may be accomplished by employing an appropriate timewise finite-difference scheme. The Houbolt operator which is a 4-point backward difference implicit operator is chosen for use in the present analysis. In this solution scheme, the $\{\ddot{q}^*\}$ at any instant of time t_m are approximated by a 4-point backward-difference expression:

$$\{\ddot{q}^*\}_m = \frac{2\{q^*\}_m - 5\{q^*\}_{m-1} + 4\{q^*\}_{m-2} - \{q^*\}_{m-3}}{(\Delta t)^2} \qquad \text{(B.35)}$$

Employing Eq. B.35, Eq. A.30+ becomes

$$\left\langle 2[M^*] + (\Delta t)^2([K]+[K_s])\right\rangle \{q^*\}_m = (\Delta t)^2 \left\langle \{\overset{*}{F}{}_q^{NL}\}_m + \{\overset{*}{F}{}_p^{L}\}_m + \{\overset{*}{F}{}_p^{NL}\}_m \right\rangle + [M^*]\left(5\{q^*\}_{m-1} - 4\{q^*\}_{m-2} + \{q^*\}_{m-3}\right) \qquad \text{(B.36)}$$

It should be noted that the generalized nodal load vectors $\{\overset{*}{F}{}_q^{NL}\}_m$, $\{\overset{*}{F}{}_p^{L}\}_m$, and $\{F_p^{*NL}\}_m$ which may be due to large-deflections and elastic-plastic effects) depend on the displacements (or stresses, strains) at that time instant t_m, but these

+Now with $\{\overset{*}{F}\} \equiv 0$.

remain to be determined; thus, linear extrapolation[+] by using the generalized nodal load vectors at two previous time steps is employed to estimate these force values. Thus, one has

$$\left\langle 2[M^*]+(\Delta t)^2([K]+[K_s])\right\rangle\{q^*\}_m = (\Delta t)^2\left(\{\overset{*}{F}{}_q^{NL}\}+\{\overset{*}{F}{}_p^{L}\}+\{\overset{*}{F}{}_p^{NL}\}\right)_{m-1}$$
$$+(\Delta t)^2\left(\{\overset{*}{F}{}_q^{NL}\}+\{\overset{*}{F}{}_p^{L}\}+\{\overset{*}{F}{}_p^{NL}\}\right)_{m-2}+[M^*]\left(5\{q^*\}_{m-1}-4\{q^*\}_{m-2}+\{q^*\}_{m-3}\right) \tag{B.37}$$

It follows that one can solve for $\{q^*\}_m$, since all of the quantities on the right-hand side are known. However, a fragment-ring collision may occur between time instants t_{m-1} and t_m; this would require a "correction" to the $\{q^*\}_m$ found from Eq. B.37. Thus, one first uses Eq. B.36 to form a trial value (overscript T):

$$\{\Delta \overset{T}{q}{}^*\}_m = \{\overset{T}{q}{}^*\}_m - \{q^*\}_{m-1} \tag{B.38}$$

Next, the collision inspection and correction procedures, which will be described in Subsection B.6, are performed to determine the actual displacement increments $\{\Delta q^*\}_m$. Then, the actual displacement at the t_m is given by

$$\{q^*\}_m = \{q^*\}_{m-1} + \{\Delta q^*\}_m \tag{B.39}$$

No such trial-and-correction procedure is needed if only prescribed external forces were applied to the containment/deflection ring.

In order to apply the calculation method represented by Eqs. B.37, one must taken into account the prescribed initial conditions, $\{q\}_o$, $\{\dot{q}\}_o$, and, if present, $\{F^*\}_o$. The following "starting procedure" for this method provides the generalized displacements $\{q^*\}$ at $t_1 = 1\Delta t$, and $\{q^*\}_{-1}$ at a negative (fictitious) time instant $t_{-1} = -1\Delta t$.

By employing the following approximations:

$$\{\dot{q}^*\}_o = \frac{2\{q^*\}_1 + 3\{q^*\}_o - 6\{q^*\}_{-1} + \{q^*\}_{-2}}{6(\Delta t)} \tag{B.40}$$

and

$$\{\ddot{q}^*\}_o = \frac{\{q^*\}_1 - 2\{q^*\}_o + \{q^*\}_{-1}}{(\Delta t)^2} \tag{B.41}$$

[+] Because of this extrapolation (aside from impact considerations themselves) the maximum time step which will lead to results of suitable engineering accuracy remain unknown but clearly is limited although the Houbolt operator itself exhibits unconditional stability.

one has

$$\{q^*\}_{-1} = (\Delta t)^2 \{\ddot{q}^*\}_o + 2\{q^*\}_o - \{q^*\}_1 \tag{B.42}$$

$$\{q^*\}_{-2} = 6(\Delta t)^2 \{\ddot{q}^*\}_o + 6(\Delta t)\{\dot{q}^*\}_o + 9\{q^*\}_o - 8\{q^*\}_1 \tag{B.43}$$

Substituting Eqs. B.42 and B.43 into Eq. B.37 for m = 1 and approximating the generalized nodal load vectors due to large-deflections and elastic-plastic effects at time step t_1 by their values at time zero, one obtains

$$\left\langle 6[M^*] + (\Delta t)^2([K^*] + [K_s^*])\right\rangle\{q^*\}_1 = (\Delta t)^2\left(\{\overset{*}{F}{}_q^{NL}\}_o + \{\overset{*}{F}{}_p^{L}\}_o + \{\overset{*}{F}{}_p^{NL}\}_o\right) + [M^*]\left\langle 2(\Delta t)^2\{\ddot{q}^*\}_o + 6(\Delta t)\{\dot{q}^*\}_o + 6\{q^*\}_o\right\rangle \tag{B.44}$$

where $\{\ddot{q}\}_o$ can be calculated from

$$[M^*]\{\ddot{q}^*\}_o = \{F^*\}_o - ([K^*] + [K_s^*])\{q^*\}_o \tag{B.45}$$

B.4 Prediction of Fragment Motion and Position

In the present analysis, the fragment is assumed (see Refs. 3,4) to be undeformable and, for analysis convenience to be circular; hence, its equations of motion for the case of no externally-applied forces are:

$$m_f \ddot{Y}_f = 0 \tag{B.46}$$

$$m_f \ddot{Z}_f = 0 \tag{B.47}$$

$$I_f \ddot{\theta} = 0 \tag{B.48}$$

where (Y_f, Z_f) and $(\ddot{Y}_f, \ddot{Z}_f)$ denote, respectively, the global coordinates and acceleration components of the center of gravity of the fragment (see Fig. B.2).

θ represents the angular displacement of the fragment in the $+\omega_f$ direction (Fig. B.2).

In timewise finite-difference form Eqs. B.46 through B.48 become

$$\left(\Delta \overset{T}{Y}_f\right)_m = \left(\Delta Y_f\right)_{m-1} \tag{B.49}$$

$$\left(\Delta \overset{T}{Z}_f\right)_m = \left(\Delta Z_f\right)_{m-1} \tag{B.50}$$

$$\left(\Delta \overset{T}{\theta}\right)_m = \left(\Delta \theta\right)_{m-1} \tag{B.51}$$

where overscript "T" signifies a trial value which requires modification, as explained later, if ring-fragment collision occurs between t_{m-1} and t_m.

By an inspection procedure to be described shortly, the instant of ring-fragment collision is determined, and the resulting collision-induced velocities which are imparted to the fragment and to the affected ring segments are determined in accordance with the analysis of Subsection B.2.

B.5 Collision Inspection and Solution Procedure

B.5.1 One-Fragment Attack

The collision inspection and solution procedure will be described first for the case in which only one idealized fragment is present. With minor modifications, this procedure can also be applied for an n-fragment attack as discussed in Subsection B.5.2.

Equation B.37 can be rewritten as follows

$$\left\langle 2\left[M^*\right] + (\Delta t)^2\left(\left[K^*\right] + \left[K_s\right]\right)\right\rangle \left\{q^*\right\}_{m+1} = (\Delta t)^2 \left\langle \left\{\overset{*}{F}{}_q^{NL}\right\}_{m+1} + \left\{\overset{*}{F}{}_p^{L}\right\}_{m+1} + \left\{\overset{*}{F}{}_p^{NL}\right\}_{m+1} \right\rangle + 2\left[M^*\right]\left(\left\{q^*\right\}_m + \left\{\dot{q}^*\right\}_m \Delta t\right) \tag{B.52}$$

in order to solve for a trial value of displacements at time step m+1, knowing the quantities at time step m.

The following procedure, indicated in the flow diagram of Fig. 9, may be employed to predict the motions of the ring and rigid fragment, their possible collision, the resulting collision-imparted velocities experienced by each, and the subsequent motion of each body:

Step 1: Let it be assumed at time t_m that the displacements $\{q^*\}_m$, $(Y_f)_m$, and $(Z_f)_m$ and displacement increments $\{\Delta q^*\}_m k$ $(\Delta Y_f)_m$, and $(\Delta Z_f)_m$ are known. One can then calculate the strain increments $(\Delta\varepsilon)_m$ at all Gaussian stations along and through the thickness of the ring.

Step 2: Using a suitable constitutive relation for the ring material, the stress increments $(\Delta\sigma)_m$ and the plastic strain increments $(\Delta\varepsilon_m^p)$ at corresponding Gaussian stations within each finite element can be determined from the known strain increments $(\Delta\varepsilon)_m$. This information permits determining all quantities on the right-hand side of Eq. 52.

Step 3: Solve Eq. B.52 for the trial ring displacements $\{\overset{T}{q^*}\}_{m+1}$, then solve for the trial displacement increments, $\{\overset{T}{\Delta q^*}\}_{m+1}$, by using Eq. B.38, and use Eqs. B.49 through B.51 for the trial fragment displacement increments $(\Delta\overset{T}{Y}_F)_{m+1}$, $(\Delta\overset{T}{Z}_f)_{m+1}$, and $(\Delta\overset{T}{\theta})_{m+1}$.

The ring node velocities $\{\dot{q}^*\}_m$ at time t_m are calculated by the following Houbolt expression:

$$\{\dot{q}^*\}_m = \frac{3\{q^*\}_m - 4\{q^*\}_{m-1} + \{q^*\}_{m-2}}{2\,\Delta t} \equiv \frac{3\{\Delta q^*\}_m - \{\Delta q^*\}_{m-1}}{2\,\Delta t} \qquad \text{(B.53)}$$

if an impact has <u>not</u> occurred in the previous time step (post-impact corrections will be described below).

It is assumed that the fragment velocities, $(\dot{Y}_f)_m$, $(\dot{Z}_f)_m$, and $(\dot{\theta}_f)_m$ at time t_m are known.

Since one or more ring-fragment collisions may have occurred between t_m and t_{m+1}, the following sequence of steps may be employed to determine whether or not a collision occurred and, if so, to effect a <u>correction</u> of the displacement increments of the impact-affected ring segments and of the fragment.

Step 4: In the present scheme, several collisions may occur during a given global time step $\Delta t = (t_{m+1} - t_m)$. This can be accommodated by repeating these checks until no further impacts can be found and corrected. Because the impact inspection is most conveniently carried out in the global Y,Z coordinate system, one first transforms the nodal displacement vector at time t_{m+1}, $\{q^*\}_{m+1}$, into the global Y,Z coordinate system; note that $\{q^*\}_{m+1}$ is the trial value obtained from Eq. B.52. The fragment information is already in the global Y,Z system and the values at time t_{m+1} are found from the following equations:

$$
\begin{aligned}
(Y_f)_{m+1} &= (Y_f)_m + (\dot{Y}_f)_m \Delta t \\
(Z_f)_{m+1} &= (Z_f)_m + (\dot{Z}_f)_m \Delta t \\
(\theta_f)_{m+1} &= (\theta_f)_m + (\dot{\theta}_f)_m \Delta t
\end{aligned}
\tag{B.54}
$$

Having completed these initializations, the following sequence of substeps may be employed to determine whether or not a collision occurs within the Δt.

Step 4a: To check for the possibility of a collision between the fragment and ring element j (approximated as a straight beam) as depicted in Fig. B.5, compute the trial projection $(\overset{T}{p}_j)_{m+1}$ of the line from <u>ring node</u> j to point C_f at the center of the fragment, upon the straight line connecting ring nodes j and j+1, as follows, at time instant t_{m+1}:

$$
\begin{aligned}
(\overset{T}{P}_j)_{m+1} = {} & (\overset{T}{Y}_j - \overset{T}{Y}_f) \cos(\overset{T}{\delta}_j)_{m+1} \\
& + (\overset{T}{Z}_j - \overset{T}{Z}_f) \sin(\overset{T}{\delta}_j)_{m+1}
\end{aligned}
\tag{B.55}
$$

where $(\overset{T}{\delta}_j)_{m+1}$ is the angle measured counterclockwise from the global Y axis to the vector from node j to node j+1 and where the Y,Z are inertial Cartesian coordinates obtained from

$\overset{T}{\{q^*\}}_{m+1}$, $\overset{T}{(Y)}_{m+1}$ etc. Now, examine $(\overset{T}{p}_j)_{m+1}$; three cases are illustrated in Fig. B.5a.

__Step 4b:__ If $(\overset{T}{p}_j)_{m+1} < 0$ or if $(\overset{T}{p}_j)_{m+1} > \ell_j$ where $\ell_j > 0$, a collision between the fragment and ring element j is impossible. Proceed to check ring element j+1, etc., for the possibility of a collision of the fragment with other ring elements. Note that ℓ_j is the length of the jth element at time t_{m+1}.

__Step 4c:__ If $0 \leq (\overset{T}{p}_j)_{m+1} \leq \ell_j$, a collision with ring element j is possible, and further checking is pursued. Next, calculate the fictitious "penetration distance" $(\overset{T}{a}_j)_{m+1}$ of the fragment into ring element j at point C_r by (see Fig. B.5b):

$$(\overset{T}{a}_j)_{m+1} = \left[\frac{1}{4}\left(h_{1j} + h_{2j}\right) + r_f\right]_{m+1} - \left[\overset{T}{d}_j\right]_{m+1} \quad \text{(B.56)}$$

where

$[\frac{1}{4}(h_{1j} + h_{2j})]$ = average distance from the reference surface to the inner surface of the ring element which is approximated as a straight beam in this "collision calculation".

r_f = radius of the fragment

$$\left[\overset{T}{d}_j\right]_{m+1} = -\left[\overset{T}{Y}_j - \overset{T}{Y}_f\right]_{m+1} \sin\left(\overset{T}{\delta}_j\right)_{m+1} + \left[\overset{T}{Z}_j - \overset{T}{Z}_f\right]_{m+1} \cos\left(\overset{T}{\delta}_j\right)_{m+1} \quad \text{(B.57}$$

= the projection of the line connecting node j with the center of the fragment upon a line perpendicular to the line joining nodes j and j+1.

Next, examine $(\overset{T}{a}_j)_{m+1}$ which is indicated schematically in Fig. 5b and is given by Eq. B.56.

Step 5: The impact with the largest penetration is corrected first. The fragment and nodal position are returned to their location at the beginning of the time step, i.e., time t_m. Then, the impact is <u>always</u> assumed to occur at the <u>beginning</u> of a time step regardless of when the "actual" time of contact occurred.

Based on the collision-interaction analysis developed in Subsection B.2, the post-impact velocities of the impact-affected ring nodes and the fragment are now calculated. That is, the pre-impact nodal velocities ($\{\dot{q}^*\}$ at time $t = t_m$) and fragment velocities ($\dot{Y}_f$, $\dot{Z}_f$, $\dot{\theta}_f$ at time $t + t_m$) are updated to their post-impact values using Eqs. B.31 through B.34.

(Note that Eqs. B.31-B34 are written in terms of an N,T coordinote system, as defined in Subsection B.2. Thus, the nodal and fragment velocities, assumed to be in the global Y,Z coordinate system prior to the collision-interaction analysis, must be transformed into the N,T system at the start of the collision-interaction analysis, and the resulting post-impact velocities, calculated in the N,T system via Eqs. B.31-B.34, must then be transformed back to the global Y,Z system after completion of the collision-interaction analysis.)

For convenience, the post-impact velocity information, in the global Y,Z coordinate system, is assumed to "replace" the pre-impact velocity information. Thus, the quantities $\{\dot{q}^*\}_m$, $(\dot{Y}_f)_m$, $(\dot{Z}_f)_m$, and $(\dot{\theta}_f)_m$ <u>now</u> refer to the post-impact velocity of the ring-nodes and fragment at the time of "assumed contact", t_m.

Step 6: A new trial displacement $\{q^*\}_{m+1}$ is now calculated using Eq. B.52 and the new post-impact-corrected nodal velocities $\{\dot{q}^*\}_m$.

Step 7: A decision must now be made concerning whether or not to continue on to another collision inspection. The collision inspection/correction process is repeated if the number of collision inspection/corrections within the current Δt has not exceeded a specified maximum[+] (equal to 5 per fragment in the present analysis). If this condition is violated, the program will immediately proceed to Step 8. Otherwise, the program proceeds to Step 4.

Step 8: The delta quantities are now calculated for both the nodal and fragment displacements (i.e., $\{\Delta q^*_{m+1}\} = \{q_{m+1}\} - \{q_m\}$; this calculation occurs regardless of whether or not an impact occurred during the time step). The program now returns to the MAIN subprogram.

Step 9: The nodal velocities at time t_{m+1} are now calculated. If no impact occurred during the previous time step, then Eq. B.53 is used to calculate $\{\dot{q}^*\}_{m+1}$. However, if impact occurred in the previous cycle, then Eq. B.53 is modified for all of the translational velocities[++] only. To find $\{q^*\}_{m+1}$ from Eq. B.53, it is necessary to know $\{q^*\}_{m-1}$. This quantity, as previously stored by the program, has no meaningful value because impact has occurred since t_{m-1}. To approximate $\{q^*\}_{m-1}$ a definition is given for the post-impact velocity $\{\dot{q}^*\}_m$ as follows:

$$\{\dot{q}^*\}_m = \frac{\{q^*\}_{m+1} - \{q^*\}_{m-1}}{2\,\Delta t} \tag{B.58}$$

Solving Eq. B.58 for $\{q^*\}_{m-1}$ and substituting this value into Eq. B.53, the following expression for the updated translational

[+]The specified maximum has been included to prevent the program endlessly looping at this point due to the use of a large Δt by the user and the fact that internal forces ($\{F^{*NL}_q\}$, $\{F^{*L}_p\}$, and $\{F^{*NL}_p\}$) in Eq. B.52 are extrapolated quantities, not updated within a Δt.

[++]Velocities associated with D.O.F.'s ψ and χ are still calculated using Eq. B.53 only.

velocities is found:

$$\left\{\dot{q}^{*}\right\}_{m+1} = \frac{2}{\Delta t}\left(\left\{q^{*}\right\}_{m+1} - \left\{q^{*}\right\}_{m}\right) - \left\{\dot{q}^{*}\right\}_{m} \tag{B.59}$$

At this point, a new set of strains is calculated and used to find the internal forces. With this quantity and the velocity at t_{m+1}, a trial value of $\{q^*\}_{m+2}$ can be obtained from Eq. B.52 and the program returns to Step 4.

This solution procedure may be carried out for as man time steps as desired or may be terminated by invoking the use of a termination criterion such as, for example, the reaching of a critical value of the strain at the inner surface or the outer surface of the ring. Appropriate modifications of this approximate analysis could be made, if desired, to follow the behavior of the ring and the fragment after the initiation and/or completion of local fracturing of the ring has occurred; however, this has not been done in the present program.

Finally, note that it is possible for the fragment to come in contact with two ring elements simultaneously. In this situation, a correction would be made for the lower-numbered element first as noted in Step 5. A "flag" is set to indicate a simultaneous impact and these corrections are made <u>before</u> Step 6 is executed. A similar situation occurs when multiple fragments impact the ring simultaneously, as will be discussed in the next subsection.

B.5.2 N-Fragment Attack

In the case of "attack" by n idealized fragments, each with its individual m_f, I_f, r_f, ω_f, V_{fN}, and V_{fT}, a similar procedure is used. During each Δt, the collision-inspection procedure is carried out for every fragment; none, some, or all of these n fragments may have collided with one or more of the ring segments. If any positive penetration distances are computed, the calculation of ring-fragment contact time will follow for each element and each of the n fragments in turn. This calculation sequence will identify the <u>first</u> ring-fragment contact within Δt, and the fragment number and element number involved in the collision. The appropriate corrections, as a result of this collision,

will be made, and the process will be repeated. The same fragment or a different fragment may collide with the ring structure; the appropriate corrections will then be made for this collision. This process is repeated until (1) more than 5 ring-fragment collisions occur for a given fragment, or (2) no more ring-fragment collisions are found within the global time step, Δt. After all of the corrections have been carried out for the present Δt time intervals, the calculation process of Fig. 9 proceeds similarly for the next Δt.

Note that it is possible for two or more fragments to impact the ring structure simultaneously. This plausible situation is accommodated in the present scheme. Because of the "flagging" scheme discussed in the previous subsection, the collision involving the lower fragment number will be corrected for first. Corrections will be made for all fragments involved in the simultaneous impact, before Step 6 is executed. In essence, the ring structure and fragment positions remain unaltered while a series of corrections is made, corresponding to all of the fragments which impact simultaneously.

Finally, it should be noted that no provisions have been made for collisions (or interactions) between the fragments themselves. Thus, all collisions (and subsequent interactions) are assumed to be between a fragment and the ring structure.

B.6 Ring-Fragment Collision on or Near a Constrained Node

The impact-interaction analysis presented in Subsection B.2 is based on the assumption that all nodes within the impact-affected region are free to respond with velocity changes as a result of ring-fragment collision. If any of the nodes within the impact-affected region are constrained, then the analysis of Subsection B.2 must be modified slightly. These modifications, and their subsequent application to the present analysis, are described in the present subsection.

For the present analysis, assume that one of the nodes within the impact-affected region is constrained such that no normal or tangential motion is permitted. Denote this node number by the subscript "c". At node c, the constraint will contribute a reaction force (or reaction impulse) so that the translational impulse-momentum relations (Eqs. B.7 and B.9) at node c must now be written as

$$m_c\left[V'_{CN} - V_{CN}\right] = \alpha_c \tilde{p}_N - p_N^R \tag{B.60a}$$

$$m_c\left[V'_{CT} - V_{CT}\right] = \alpha_c \tilde{p}_T - p_T^R \tag{B.60b}$$

where the additional terms p_N^R and p_T^R are the reaction impulses at node c in the normal and tangential directions, respectively. The pre-impact velocities, V_{CN} and V_{CT}, must be zero and because of the constraint, the post-impact velocities must also be zero, thus Eqs. B.60 state that the restraint "absorbs" all of the impulse associated with the constrained node.

The analysis developed in Subsection B.2 can be followed exactly if the value of α for the constrained node is set equal to zero, i.e.

$$\alpha_c = 0 \tag{B.61}$$

This is equivalent to introducing equations of the form of Eq. B.60 and immediately solving for the reaction impulse, which yields a total value of zero on the right-hand side of Eq. B.60. In practice, the use of Eq. B.61 allows one to treat the special case of impact on or near a constrained node within the framework and equations developed in Subsection B.2.

It should be noted that the quantity α' for the constrained node is not set equal to zero. This quantity defines the relative portion of the total imparted impulse which is associated with a given node which lies within the impact-affected region, and is calculated by using Eq. A.31 whether or not the node is constrained. In general, the constrained node may fall anywhere within the impact-affected region. Because of the character of the present impact interaction analysis in which only translational (not rotational) motion of the ring is considered (both translational and rotational motion are included in the global timewise solution), it is difficult to include the effects of impulse propagated past the constrained node. For the case where the node is ideally clamped, no information can propagate through the constraint. But if the node is pinned-fixed, rotational information could propagate past the constraint; to accommodate this situation, rotational

effects would have to be included in the analysis of Subsection B.2. An alternate, interim measure is taken in the present analysis, and is described next.

Assume that the point of contact and the effective length, L_{eff}, are such that the constrained node and nodes beyond the constrained node fall within the impact-affected region. Because the analysis of Subsection B.2 cannot predict the propagation of impact information past the constrained node, the effective length, L_{eff}, is, in the present scheme, artificially reduced (for the current Δt only) in such a way that the constrained node falls within the impact-affected region but no nodes past the constrained node fall in the impact-affected region. Having redefined L_{eff} in this fashion, the equations of Subsection B.2 are then followed exactly with Eq. B.61 being employed at the constrained node. This approach has the effect of concentrating the impact-induced impulse at those ring nodes on the impacted side of the constraint, with a portion of the impact-induced impulse being absorbed by the constraint, and no impulse being felt at nodes beyond the constrained node. However, it should be recognized that, although no impulse information is passed through the constrained node by the impact interaction analysis, the impact information will propagate through the constrained node, if physically possible, in the global timewise structural response solution.

For the case where impact occurs directly on a constrained node, only that constrained node is assumed to lie within the impact-affected region. Following the equations in Subsection B.2 and employing Eq. B.61, the fragment will simply rebound (as if impacting a rigid wall) and the ring structure will experience no momentum changes for this impact.

Finally, it should be noted that the present approach is an interim measure, and further effort is required to develop a more comprehensive approach for treating impact near a constrained node. However, the present method is believed to be sufficiently general, within the current overall assumptions of the analysis, to yield reasonable results for current engineering applications.

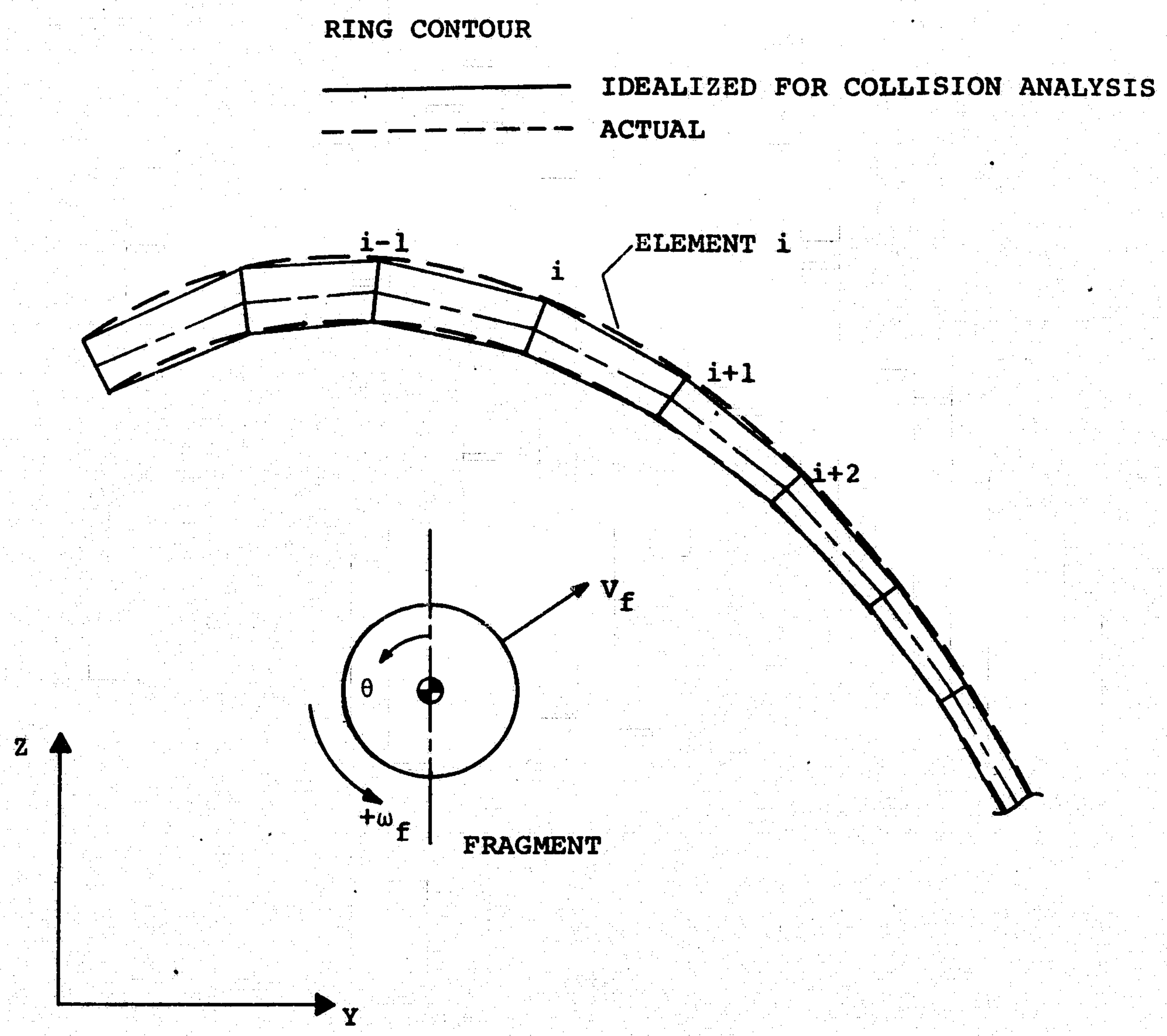
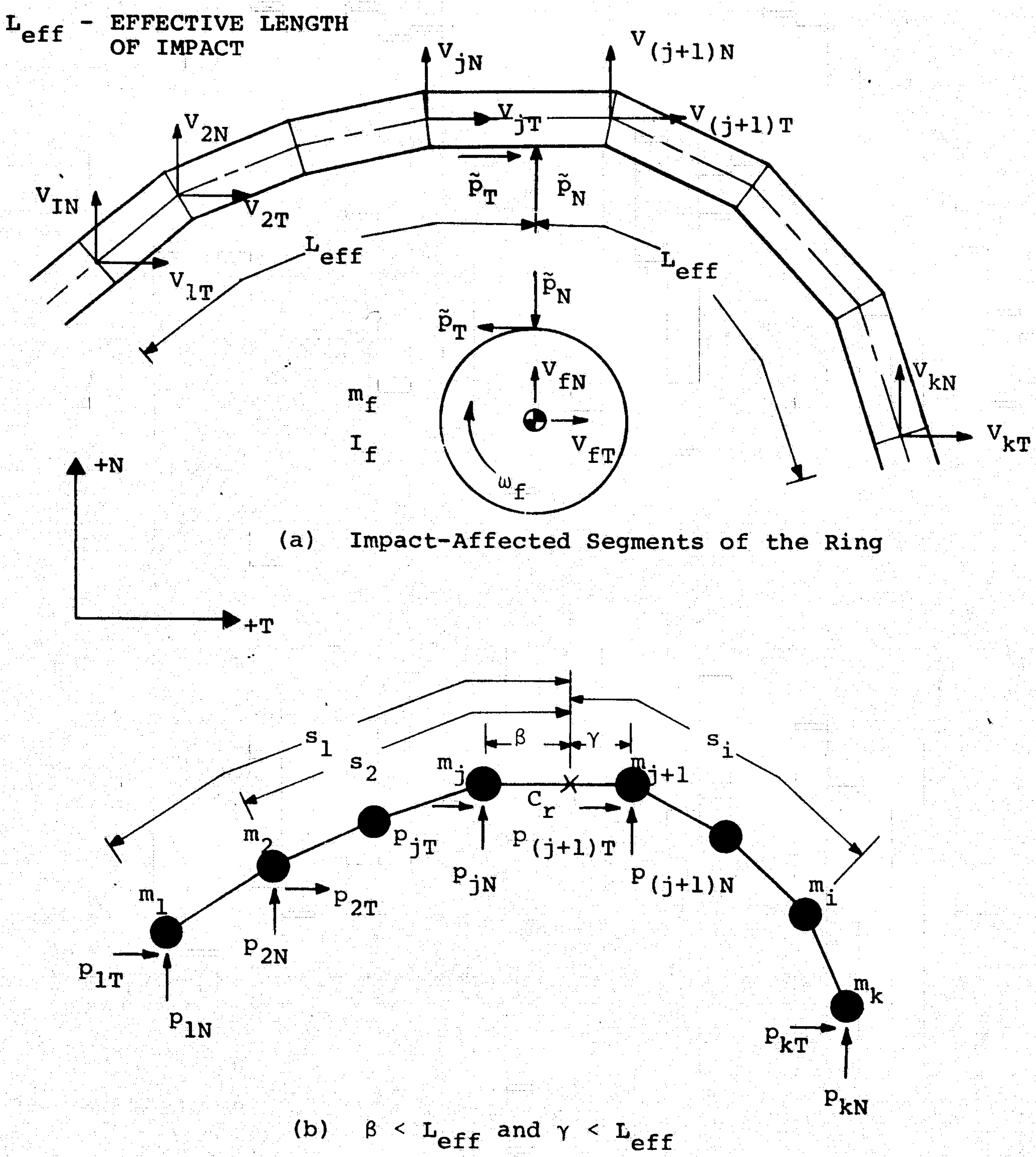


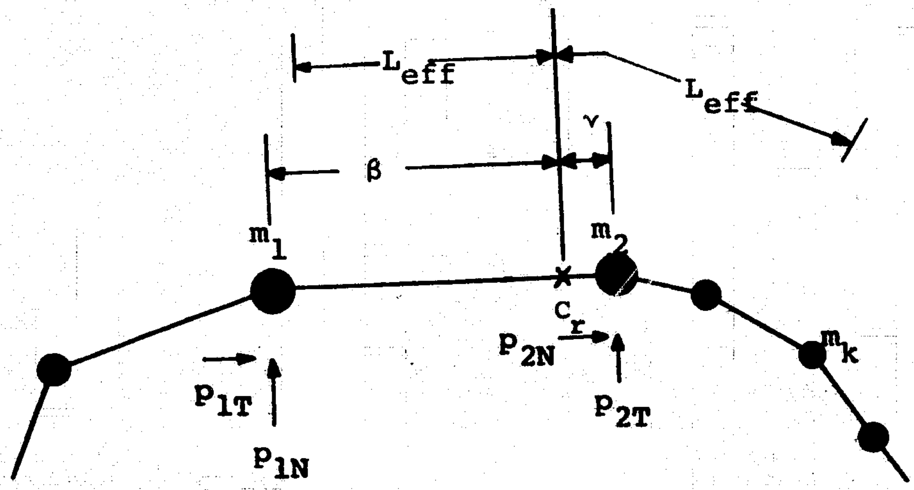
FIG. B.1 IDEALIZATION OF RING CONTOUR FOR COLLISION ANALYSIS



(a) Impact-Affected Segments of the Ring

(b) $\beta < L_{eff}$ and $\gamma < L_{eff}$

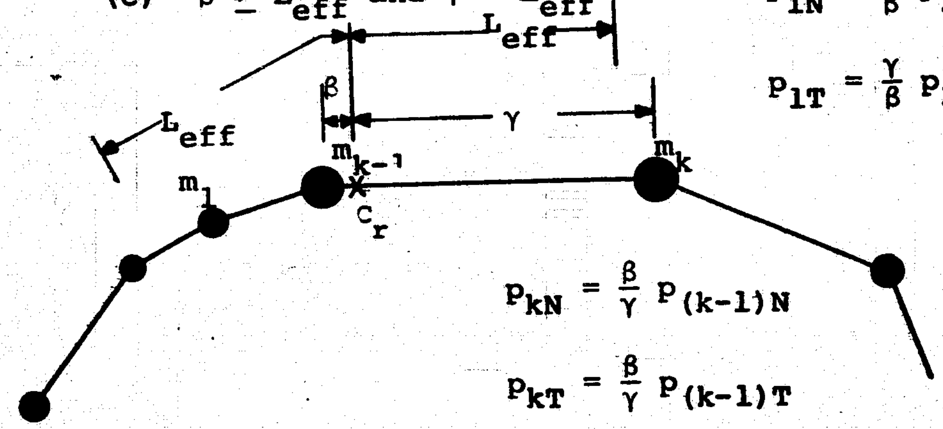
FIG. B.2 EXPLODED SCHEMATICS OF THE LUMPED-MASS COLLISION MODELS



(c) $\beta \geq L_{eff}$ and $\gamma < L_{eff}$

$$p_{1N} = \frac{\gamma}{\beta}\, p_{2N}$$

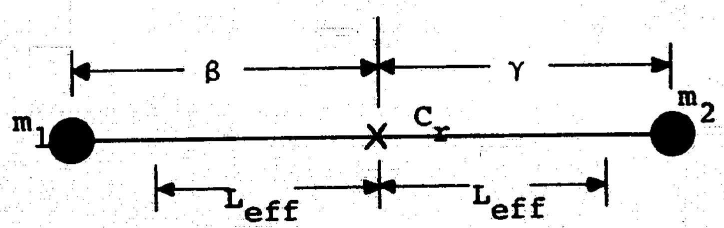
$$p_{1T} = \frac{\gamma}{\beta}\, p_{2T}$$



$$p_{kN} = \frac{\beta}{\gamma}\, p_{(k-1)N}$$

$$p_{kT} = \frac{\beta}{\gamma}\, p_{(k-1)T}$$

(d) $\beta < L_{eff}$ and $\gamma \geq L_{eff}$



$$p_{1N} = \frac{\gamma}{\beta+\gamma}\, \tilde{p}_N$$

$$p_{1T} = \frac{\gamma}{\beta+\gamma}\, \tilde{p}_T$$

$$p_{2N} = \frac{\beta}{\beta+\gamma}\, \tilde{p}_N$$

$$p_{2T} = \frac{\beta}{\beta+\gamma}\, \tilde{p}_T$$

(e) $\beta \geq L_{eff}$ and $\gamma \geq L_{eff}$

FIG. B.2 CONCLUDED

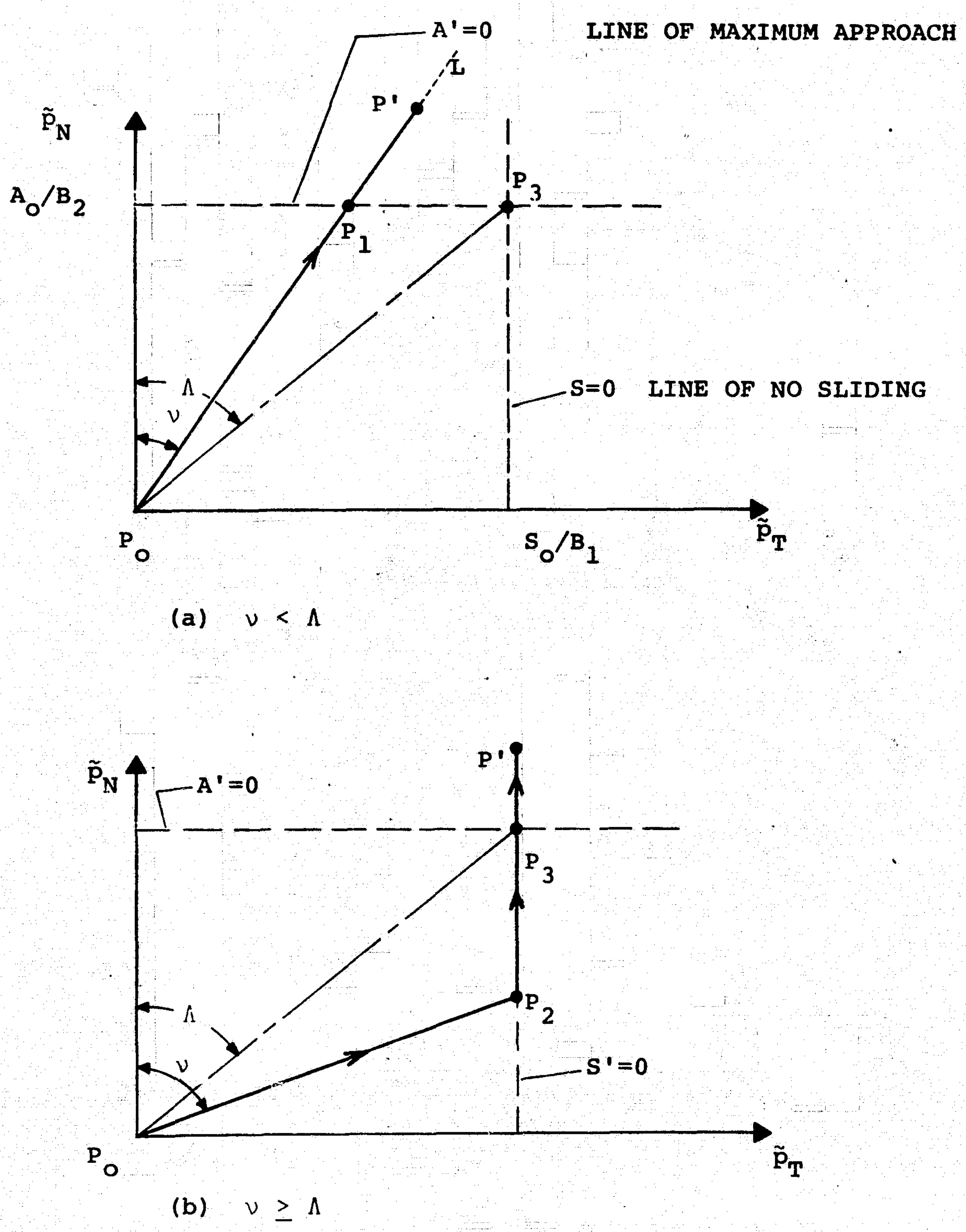


FIG. B.3 THE TRAJECTORY OF THE IMAGE POINT $\overline{P}$ IN THE $\tilde{p}_N$, $\tilde{p}_T$ PLANE TO DESCRIBE THE STATE AT EACH CONTACT INSTANT

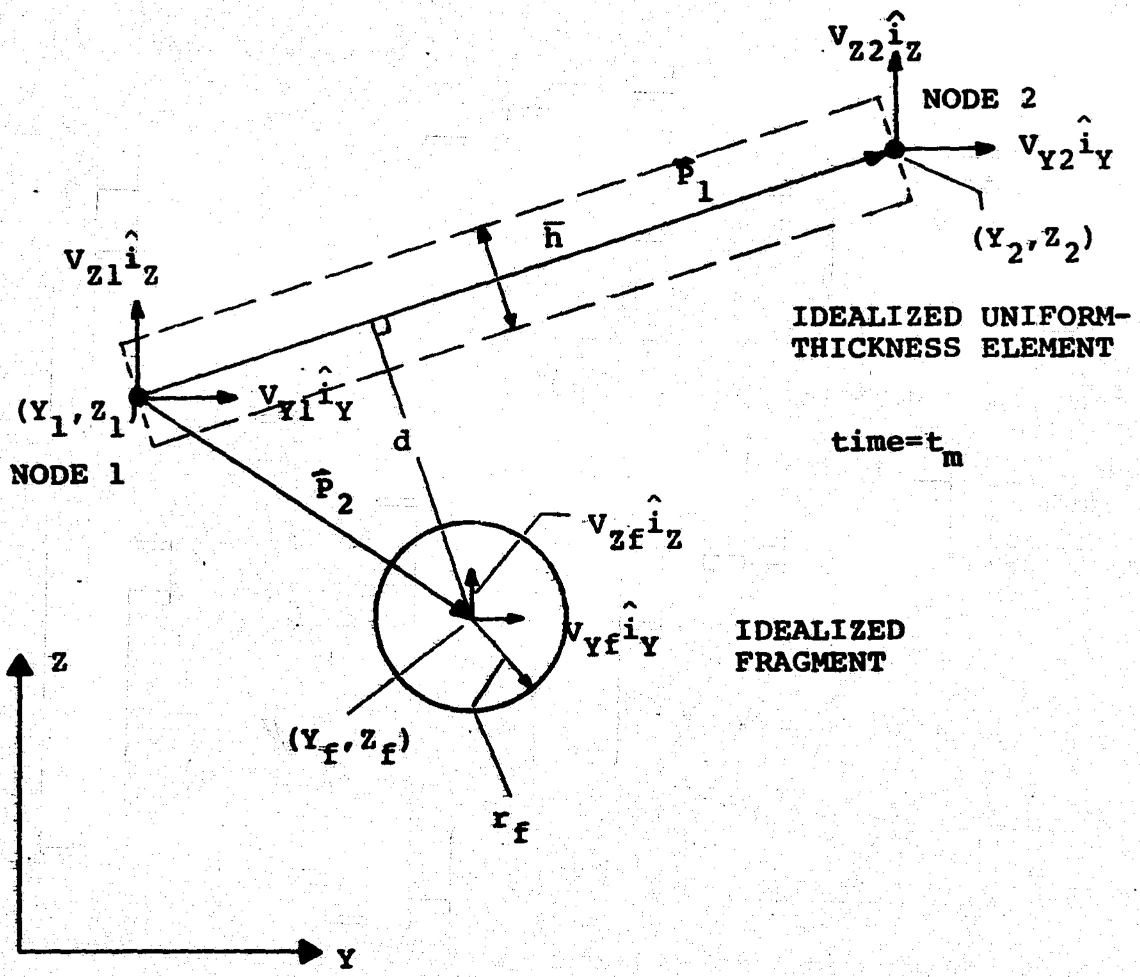


FIG. B.4 IDEALIZATIONS AND DEFINITIONS FOR CALCULATION OF TIME OF RING-FRAGMENT CONTACT

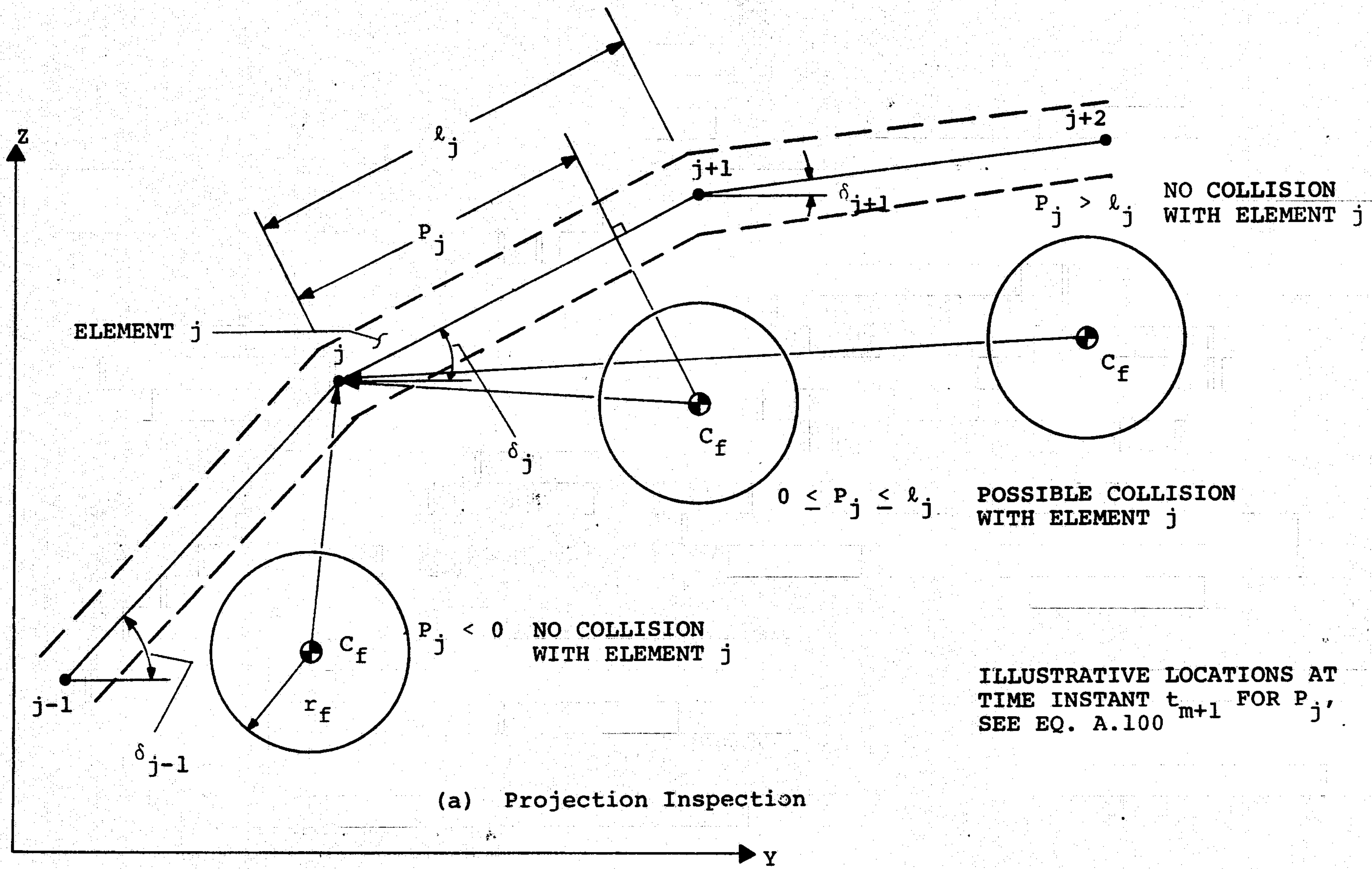
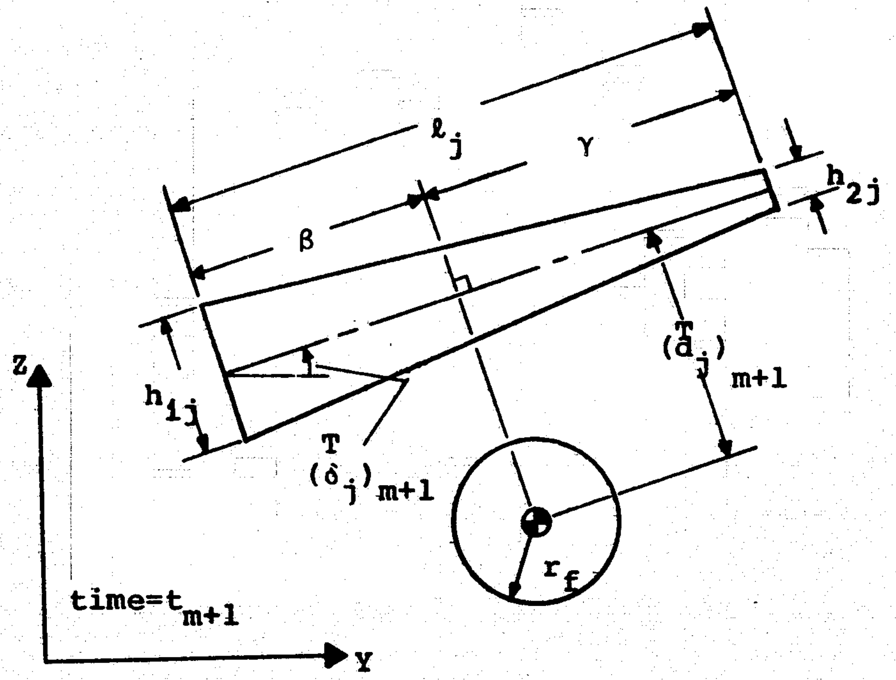
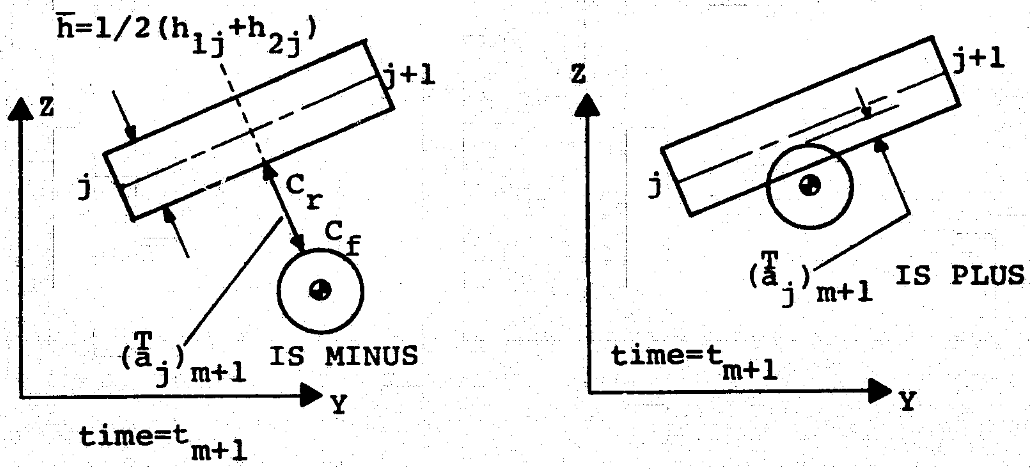


FIG. B.5 INSPECTION FOR DETERMINING A COLLISION OF THE FRAGMENT WITH THE RING



IDEALIZED UNIFORM-THICKNESS ELEMENT



(b) Penetration Inspection

FIG. B.5 CONCLUDED

APPENDIX C

SUMMARY OF THE CAPABILITIES OF MIT-ASRL COMPUTER CODES FOR PREDICTING TWO-DIMENSIONAL LARGE-DEFLECTION ELASTIC-PLASTIC TRANSIENT RESPONSES OF RING STRUCTURES

This description is intended to provide for the reader a convenient tabular summary of the principal features and capabilities of the two-dimensional transient large-deflection elastic-plastic structural response ring codes JET 1 (Ref. 1*), JET 2 (Ref. 2), JET 3A-3D (Ref. 3), CIVM-JET 4B (Ref. 4), and JET 5A and CIVM-JET 5B (Ref. 5) developed under NASA NGR 22-009-339; the status of code availability is also indicated.

The JET 1 code of Ref. 1 pertains to single-layer complete, uniform-thickness, initially-circular rings of either temperature-independent or temperature dependent material properties. These rings may be subjected to prescribed: (a) initial velocities, (b) transient mechanical loading, and/or (c) steady nonuniform temperatures. The finite-difference method employed in this code had been shown previously (Ref. 6) to provide reliable predictions for the case of temperature-independent material properties.

The JET 2 code was written in order to extend this finite-difference analysis capability to treat multilayer rings -- cases anticipated to be of future concern. In the interests of efficiency and the minimization of computer storage requirements, temperature-dependent material properties and thermal loading features were omitted from JET 2; if these omitted features should turn out to be needed, they could be added later.

Since the JET 1 and JET 2 codes pertained to initially-circular, complete rings of uniform thickness whereas there was interest also in variable-thickness, arbitrarily curved, partial as well as complete rings, the JET 3 series of codes was developed. To accommodate these latter features as well as a variety of types of (1) boundary conditions, (2) elastic-foundation supports, and (3) point elastic supports, the more versatile finite-element analysis procedure was developed and employed.

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* These references are identified in the reference list at the end of Appendix C.

For efficiency and user convenience, four versions of the JET 3 program were developed; each version accommodates both complete rings and partial rings. JET 3A and JET 3B pertain to uniform-thickness, initially-circular rings, and employ, respectively, the central-difference and the Houbolt finite-difference time operator; for certain cases, the latter finite-difference time operator may permit more economic converged transient response predictions than the former. The codes JET 3C and JET 3D are corresponding codes which accommodate variable-thickness, arbitrarily-curved rings.

In most of these codes (JET 1 through JET 3D, and JET 5A), the stimuli: (1) initial velocity or impulse conditions and/or (2) transient mechanical loading must be prescribed by the user or analyst. The externally-applied forces experienced by a complete or a partial ring from fragment impact are not provided within these codes. The user must supply his own estimate of the distribution and time histories of these forces. However, in the CIVM-JET 4B and CIVM-JET 5B codes, fragment/ring interaction and response effects are handled internally automatically for the idealized single-fragment and n-fragment cases provided and discussed in the Appendices of Refs. 4, 5, and 7.

The CIVM-JET 4B code (Ref. 4) was developed from a modified version of the JET 3C code, using the central difference timewise operator. The CIVM (collision imparted velocity method) handles a fragment-structure impact as a series of quasi-static momentum transfers between the attacking fragment and the local-impact-affected portion of the impacted structure. The solution proceeds as though a series of impulses has been applied to the impacted region of the structure. This code provides strain output at each Gaussian station, nodal location, and designated "additional points" for user convenience, and calculates the reaction forces at each constrained degree of freedom. Another feature of this code is the ability to accommodate branches which are used as additional structural supports. These branches can have material properties either the same or different from those present in the main structure.

The JET 5A and CIVM-JET 5B codes (Ref. 5) were written in order to extend the capabilities of the JET 3D and CIVM-JET 4B codes to multilayer

structures which are assumed to be hard-bonded and to deform in the Bernoulli-Euler fashion. Both codes (JET 5A and CIVM-JET 5B) contain the Houbolt timewise operator as well as the additional strain and reaction force output and structural support capabilities utilized in the CIVM-JET 4B code.

In convenient tabular form, the principal features and capabilities of the codes JET 1, JET 2, JET 3A-D, CIVM-JET 4B, JET 5A, and CIVM-JET 5B are given in the tabular summary on the following pages.

With respect to predicting ring structural response to fragment impact, note that codes CIVM-JET 4B and CIVM-JET 5B apply. The former pertains only to single-layer rings and employs the central-difference time operator, while CIVM-JET 5B applies to hard-bonded multilayer Bernoulli-Euler rings (including single layer rings) and utilizes the Houbolt finite-difference time operator. Thus, for single layer rings one could use either CIVM-JET 4B or CIVM-JET 5B, whereas only CIVM-JET 5B applies to multilayer rings.

With respect to deciding which of these two codes should be chosen to analyze fragment-induced structural response of <u>single-layer</u> rings, the following can be taken into consideration. CIVM-JET 4B utilizes the very compact and efficient unconventional formulation of the ring's equations of motion and hence involves minimum computations and storage per time step of calculation; on the other hand, this code utilizes the central difference time operator whose maximum time step size is limited to about $\Delta t_{max} \leq 1.6/\omega_{max}$ where ω_{max} is the highest frequency of the linear elastic behavior of the structural model employed, unless impact-interaction convergence dictates a smaller value -- a condition not encountered thus far in calculation examples explored. Since CIVM-JET 5B uses the conventional form of the ring's equations of motion, more computations and storage per time step of calculation are needed than in CIVM-JET 4B; however, CIVM-JET 5B employs the Houbolt finite-difference time operator which permits one to use a time step size Δt larger by a factor of perhaps 3 to 10 or more than permitted by CIVM-JET 4B's central-difference operator unless the impact-interactions and convergence impose a more stringent limit. Because of these tradeoffs, it is not clear which of these two codes will be the more

efficient one for obtaining reliable converged predictions of impact-induced structural response of single-layer rings; it appears that further computational experience on various example problems will be needed before a clear choice can be made. However, on an equal-cost basis, experience to date indicates that one must use for CIVM-JET 5B a Δt at least 5 times as large as the maximum time step size permitted in CIVM-JET 4B to be competitive. In one example a 10-times larger Δt resulted in a CIVM-JET 5B prediction that failed to converge. Thus, until further computational experience has accumulated sufficiently, it would be advisable to begin with CIVM-JET 4B for analyzing "new problems" unless an intolerably small Δt is encountered, since this code exhibits usually a dramatic warning (computational blow up) when the chosen Δt is too large, whereas CIVM-JET 5B does not usually afford clear telltale signs of ill-behaved computations. With this CIVM-JET 4B starting point as guidance, one could explore the utility of employing CIVM-JET 5B with a time step size of perhaps 5 to 10 times larger.

For the analysis of ring response to prescribed external transient loads or to prescribed distributions of initial velocity (rather than fragment impact-induced response), similar considerations to those just discussed apply concerning the analysis of single-layer rings by JET 3C (which uses the central difference time operator) versus JET 5A (which employs the Houbolt operator); for these kinds of problems, experience to date indicates that response predictions of a given accuracy can be obtained more efficiently by using JET 5A's larger allowable Δt (i.e. by a factor of perhaps 6 to 10 or more than permitted by JET 3C). Finally, even for the analysis of single-layer rings for this class of (non-impact) problems, the use of the more recent and versatile JET 5A computer program is recommended over the use of JET 3D even though both of these codes employ the Houbolt operator.

Feature	JET 1 (Ref.1)	JET 2 (Ref.2)	JET 3A (Ref.3)	JET 3B (Ref.3)	JET 3C (Ref.3)	JET 3D (Ref.3)	CIVM-JET 4B (Ref.4)	JET 5A (Ref.5)	CIVM-JET 5B (Ref.5)
Type of Spatial Analysis Formulation									
Finite Difference	x	x	-	-	-	-	-	-	-
Finite Element	-	-	x	x	x	x	x	x	x
Type of Finite-Difference Time Operator									
Central Difference	x	x	x	-	x	-	x	-	-
Houbolt (Backward Difference)	-	-	-	x	-	x	-	x	x
<u>Ring Geometry</u>									
Complete Ring	x	x	x	x	x	x	x	x	x
Partial Ring	-	-	x	x	x	x	x	x	x
<u>Initial Configuration</u>									
Circular	x	x	x	x	x	x	x	x	x
Arb. Curved	-	-	-	-	x	x	x	x	x
Constant Thickness	x	x	x	x	x	x	x	x	x
Variable Thickness	-	-	-	-	x	x	x	x	x
Single Layer	x	x	x	x	x	x	x	x	x
Multilayer Hard-Bonded (1 to 3 layers)	-	x	-	-	-	-	-	x	x
<u>Boundary Conditions</u>									
Ideally Clamped	-	-	x	x	x	x	x	x	x
Hinged Fixed	-	-	x	x	x	x	x	x	x
Symmetry	-	-	x	x	x	x	-	x	-
Free	-	-	x	x	x	x	x	x	x
<u>Other Support Conditions</u>									
Distributed Elastic Foundation	-	-	x	x	x	x	x	x	x
Point Elastic Springs	-	-	x	x	x	x	x	x	x
Structural Branch	-	-	-	-	-	-	x	x	x

Feature	JET 1	JET 2	JET 3A	JET 3B	JET 3C	JET 3D	CIVM-JET 4B	JET 5A	CIVM-JET 5B
Material									
Single Material	x	-	x	x	x	x	x	x	x
Different for Each Layer	-	x	-	-	-	-	-	x	x
Homogeneous	x	x	x	x	x	x	x	x	x
Initially Isotropic	x	x	x	x	x	x	x	x	x
Temperature Independent	x	x	x	x	x	x	x	x	x
Temperature Dependent	x	-	-	-	-	-	-	-	-
EL	x	x	x	x	x	x	x	x	x
EL-PP	x	x	x	x	x	x	x	x	x
EL-LSH	x	x	x	x	x	x	x	x	x
EL-SH	x	x	x	x	x	x	x	x	x
EL-SH-SR	x	x	x	x	x	x	x	x	x
Stimulii									
Initial Velocity									
Arbitrary	x	x	x	x	x	x	-	x	-
Half-Sine over each of Selected Regions	x	x	x	x	x	x	-	x	-
Mechanical Loading									
Arbitrary Spatial Distribution with Arb. Time History	-	x	x	x	x	x	-	x	-
Half-Sine over each of Selected Regions	x	x	x	x	x	x	-	x	-
Triangular Time History	x	x	x	x	x	x	-	x	-
Arbitrary Time History	-	x	x	x	x	x	-	x	-
Thermal Loads (Temp. Distribution)									
Distribution Thru Thickness	x	-	-	-	-	-	-	-	-
Time-Independent Prescribed Circumferential Distribution	x	-	-	-	-	-	-	-	-
Impacting Fragments									
Single	-	-	-	-	-	-	x	-	x
Multiple	-	-	-	-	-	-	x	-	x
Friction	-	-	-	-	-	-	x	-	x

Feature	JET 1	JET 2	JET 3A	JET 3B	JET 3C	JET 3D	CIVM-JET 4B	JET 5A	CIVM-JET 5B
<u>Deflections: Bernoulli-Euler Type Only</u>									
Small	x	x	x	x	x	x	x	x	x
Arbitrarily Large	x	x	x	x	x	x	x	x	x
OUTPUT INFORMATION									
<u>At Selected Times</u>									
Energy/Work Type and Amount	x	x	x	x	x	x	x	x	x
Nodal Station Data									
Locations Y,Z	x	x	x	x	x	x	x	x	x
Displacements	-	-	x	x	x	x	x	x	x
Moment Resultant	x	x	x	x	x	x	x	x	x
Circum. Force Resultant	x	x	x	x	x	x	x	x	x
Circumferential Strains									
Inner Surface	x	x	x	x	x	x	x	x	x
Outer Surface	x	x	x	x	x	x	x	x	x
Location where Prescribed Value is Exceeded	-	x	x	x	x	x	-	-	-
Strain at Gaussian Stations	-	-	-	-	-	-	x	x	x
Strain at Additional Location	-	-	-	-	-	-	x	x	x
Support Reaction Forces	-	-	-	-	-	-	x	x	x
<u>At Certain Other Times</u>									
Time of First Yielding	x	x	-	-	-	-	-	-	-
Time when Strain First Exceeds a Prescribed Value	-	x	x	x	x	x	-	-	-
Time, Location, and Value of Largest Strain Reached During Run	-	-	x	x	x	x	x (For Each Substructure)	x (For Each Substructure)	x (For Each Substructure)
CAPACITY INFORMATION									
Maximum No. of Finite-Difference Stations*	100	100	-	-	-	-	-	-	-
Maximum No. of Finite Elements*	-	-	50	50	50	50	50	50	50

*These limits can be circumvented by altering the dimensions of appropriate program variables (see each source reference).

STRUCTURAL RESPONSE COMPUTER CODE STATUS[c]

Code	Capability	Status	Availability
JET 3	2-D Single-Layer Beams and Rings Subjected to Prescribed Transient Loads or Initial Velocity Distributions (No Fragment Impact)	Complete (Ref. 3)	a
CIVM-JET 4B	2-D Single-Layer Beams and Rings Subjected Only to Fragment Impact	Complete (Ref. 4)	b
JET 5A	2-D Multilayer Bernoulli-Euler Beams and Rings Subjected to Prescribed Transient Loads or Initial Velocity Distributions	Complete (Ref. 5)	b
CIVM-JET 5B	2-D Multilayer B-E Beams and Rings Subjected Only to Fragment Impact	Complete (Ref. 5)	b
PLATE and CIVM-PLATE	3-D Single-Layer Initially-Flat Panels Subjected, Respectively, to (1) Prescribed Transient Loads and/or Initial Velocity Distributions or (2) Fragment Impact Only	In Progress	--

a: Available from COSMIC, Barrow Hall, University of Georgia, Athens, GA. 30601; contact MIT for errata.

b: Available under a copyright licensing agreement from MIT. Contact Prof. E.A. Witmer, Room 41-219, MIT, Cambridge, MA. 02139.

c: JET1(Ref. 1) and JET 2 (Ref. 2) have not been maintained and are available only from the listings in the cited references; in turn, these references are available only from the National Technical Information Service (NTIS), Springfield, VA. 22161.

REFERENCES FOR APPENDIX C

1. McCallum, R.B., Leech, J.W. and Witmer, E.A., "Progress in the Analysis of Jet Engine Burst-Rotor Containment Devices", ASRL TR 154-1, Aeroelastic and Structures Research Laboratory, Massachusetts Institute of Technology, August 1969. (Available as NASA CR-107900.)

2. McCallum, R.B., Leech, J.W. and Witmer, E.A., "On the Interaction Forces and Responses of Structural Rings Subjected to Fragment Impact", ASRL TR 154-2, Aeroelastic and Structures Research Laboratory, Massachusetts Institute of Technology, September 1970. (Available as NASA CR-72801.)

3. Wu, R.W.-H. and Witmer, E.A., "Computer Program - JET 3 - to Calculate the Large Elastic-Plastic Dynamically-Induced Deformations of Free and Restrained, Partial and/or Complete Structural Rings", ASRL TR 154-7, Aeroelastic and Structures Research Laboratory, Massachusetts Institute of Technology, August 1972. (Available as NASA CR-120993.)

4. Stagliano, T.R., Spilker, R.L. and Witmer, E.A., "User's Guide to Computer Program CIVM-JET 4B to Calculate the Transient Structural Responses of Partial and/or Complete Structural Rings to Engine Rotor Fragment Impact", MIT ASRL TR 154-9, March 1976. (Available as NASA CR-134907.)

5. Wu, R.W.-H., Stagliano, T.R., Witmer, E.A. and Spilker, R.L., "User's Guide to Computer Programs JET 5A and CIVM-JET 5B to Calculate the Large Elastic-Plastic Dynamically-Induced Deformations of Multilayer Partial and/or Complete Structural Rings", MIT ASRL TR 154-10, November 1978.

6. Balmer, H.A. and Witmer, E.A., "Theoretical-Experimental Correlation of Large Dynamic and Permanent Deformations of Impulsively-Loaded Simple Structures", Massachusetts Institute of Technology, AFFDL-TDR-64-108, July 1964.

7. Collins, T.P. and Witmer, E.A., "Application of the Collision-Imparted Velocity Method for Analyzing the Responses of Containment and Deflector Structures to Engine Rotor Fragment Impact", ASRL TR 154-8, MIT, August 1973. (Available as NASA CR-134494.)

APPENDIX D

SUMMARY OF GAUSSIAN NUMERICAL INTEGRATION OR QUADRATURE

Gaussian numerical integration (or quadrature) is a convenient and efficient method for the numerical evaluation of line, surface, and/or volume integrals. For one-dimensional (or line) integration, Gaussian numerical n-station integration is of the form [14, Ch. 8]:

$$\int_{-1}^{+1} F(x)\,dx \doteq \sum_{j=1}^{n} H_j\, F(x_j) \qquad \text{(D.1)}$$

where

$H_1, H_2, \ldots, H_n$ are tabulated weighting factors associated with sampling locations x_j, $j=1, 2, \ldots, n$.

$F(x_j)$ represents the value of $F(x)$ at prescribed unequally-spaced "sampling stations" x_j (or $a_j \equiv x_j$) for $j=1, 2, \ldots, n$

For n-station Gaussian quadrature, polynomials of degree 2n-1 and smaller are integrated exactly [14]. Sampling locations a_j and weights H_j follow for the Gaussian numerical integration evaluation [14-17] represented by Eq. D.1 for n=2, 3, 4, 5, 6, 7, 8, 9, and 10 (values for n up to 96 may be found in Ref. 16):

Station $\pm a$		Weight H
	n = 2	
0.57735 02691 89626		1.00000 00000 00000
	n = 3	
0.77459 66692 41483		0.55555 55555 55556
0.00000 00000 00000		0.88888 88888 88889
	n = 4	
0.86113 63115 94053		0.34785 48451 37454
0.33998 10435 84856		0.65214 51548 62546

Station $\pm a$	Weight H
$n = 5$	
0.90617 98459 38664	0.23692 68850 56189
0.53846 93101 05683	0.47862 86704 99366
0.00000 00000 00000	0.56888 88888 88889
$n = 6$	
0.93246 95142 03152	0.17132 44923 79170
0.66120 93864 66265	0.36076 15730 48139
0.23861 91860 83197	0.46791 39345 72691
$n = 7$	
0.94910 79123 42759	0.12948 49661 68870
0.74153 11855 99394	0.27970 53914 89277
0.40584 51513 77397	0.38183 00505 05119
0.00000 00000 00000	0.41795 91836 73469
$n = 8$	
0.96028 98564 97536	0.10122 85362 90376
0.79666 64774 13627	0.22238 10344 53374
0.52553 24099 16329	0.31370 66458 77887
0.18343 46424 95650	0.36268 37833 78362
$n = 9$	
0.96816 02395 07626	0.08127 43883 61574
0.83603 11073 26636	0.18064 81606 94857
0.61337 14327 00590	0.26061 06964 02935
0.32425 34234 03809	0.31234 70770 40003
0.00000 00000 00000	0.33023 93550 01260
$n = 10$	
0.97390 65285 17172	0.06667 13443 08688
0.86506 33666 88985	0.14945 13491 50581
0.67940 95682 99024	0.21908 63625 15982
0.43339 53941 29247	0.26926 67193 09996
0.14887 43389 81631	0.29552 42247 14753

The above tabulation applies to $\int_{-1}^{+1} F(x)dx \doteq \sum_{j=1}^{n} H_j F(a_j)$ where $-1<a_j<1$. However, these entries can be modified to apply to any interval [a,b] as follows to evaluate:

$$\int_a^b F(x)\,dx \doteq \sum_{j=1}^{n} W_j\, F(x_j) \tag{D.2}$$

For Eq. D.2, the "new" W_j and x_j for given H_j and a_j become:

$$W_j = \frac{a+b}{2} H_j$$
$$x_j = \left(\frac{|a|+|b|}{2}\right)(1+a_j) \tag{D.2a}$$

For example, consider

$$\int_0^1 F(x)\,dx \doteq \sum_{j=1}^{n} W_j\, F(x_j) \tag{D.3}$$

Hence,

$$W_j = \left(\frac{0+1}{2}\right) H_j$$
$$x_j = \left(\frac{0+1}{2}\right)(1+a_j) \tag{D.4}$$

For the 3-station case (n=3), for example, one obtains:

j	a_j	H_j	x_j	W_j
1	-.77459...	0.55555...	0.11270166...	0.277777...
2	0	0.88888...	0.50	0.44444...
3	+.77459	0.55555...	0.8872983...	0.277777...

Similarly, one may perform Gaussian quadrature in two and three dimensions by, respectively,

$$\int_{-1}^{+1}\int_{-1}^{+1} F(\xi,\eta)\,d\xi\,d\eta \doteq \sum_{i=1}^{n}\sum_{j=1}^{m} H_i H_j\, F(\xi_i,\eta_j) \tag{D.5}$$

$$\int_{-1}^{+1}\int_{-1}^{+1}\int_{-1}^{+1} F(\xi,\eta,\zeta)\,d\xi\,d\eta\,d\zeta \doteq \sum_{i=1}^{p}\sum_{j=1}^{q}\sum_{k=1}^{r} H_i H_j H_k\, F(\xi_i,\eta_j,\zeta_k) \tag{D.6}$$

Conversions similar to those given by Eq. D.2a may be employed for other limits of integration.

For quadrature over triangles, cones, tetrahedra, etc., see Refs. 14, 15, and 17.